Contract AF 19(626)-16
System 433L
Tech. Rpt. 1

OBJECTIVE ANALYSIS of the STRATOSPHERE BASED on MID-and UPPER-TROPOSPHERIC DATA

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7 NA

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Objective Analysis of the Stratosphere,

Based on Mid- and Upper-tropospheric Data

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David B. Spiegler
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ERRATA

1. Page 6, 3rd paragraph, line 7. Delete "The 'correction'" and substitute "¶ If an observation station reports a height and a wind, the correction"

2. Page 6, 3rd paragraph, line 8. Delete "gridpoint" and substitute "location of the observation (interpolated from the four surrounding gridpoints)"

3. Page 6, 3rd paragraph, line 9. Delete "winds, and" and substitute "winds. This"

4. Page 6, 3rd paragraph, line 9. Change "the equation" to read "the corresponding equation"

5. Page 6, Eq. (2-1). Change to read

$$C = W(d)\left[\frac{S(x_s, y_s) + nZ_{obs}}{1 + n} + \frac{mkfv_0}{g}x' - \frac{mkfu_0}{g}y' - Z_{x,y}\right]. \tag{2-1a}$$

6. Page 7, 5th line from bottom. Delete "The" and substitute "¶ If a station reports a height only, the correction equation is

$$C = W(d)\left[\frac{S(x_s, y_s) + nZ_{obs}}{1 + n} - S(x_s, y_s)\right]. \tag{2-1b}$$

¶ If a station reports a wind only, Eq. (2-1a) is used, but the terms nZ_{obs} and n are omitted. ¶ The"

7.* Pages 17 and 21. Substitute revised Figs. 4-1(d) and 4-5 provided.

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*Result of machine error.

8.* Pages 79 and 80. Substitute the following equations for 45—55°N:

250 mb $Z_0 = 588.77 + 0.96044\,(300Z_0) + 1.7419\,(300T_0)$

250 mb $T_0 = -\ 511.33 + 1.0568\,(250Z_0) - 1.0568\,(300Z_0) - 0.96757\,(300T_0)$

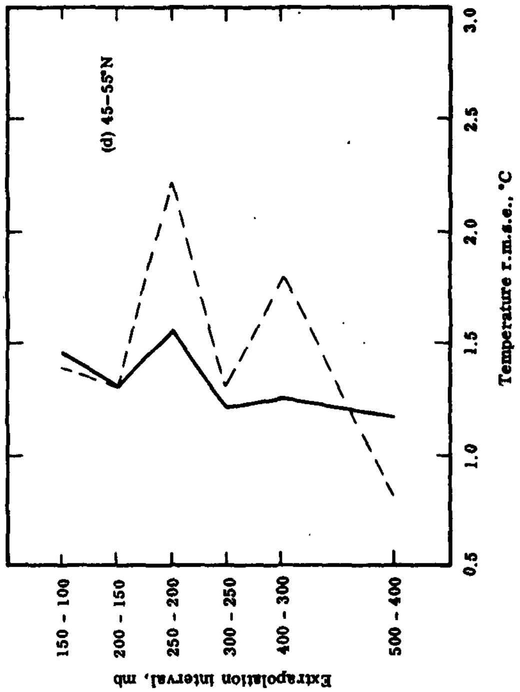
200 mb $Z_0 = 734.04 + 0.95107\,(250Z_0) + 1.9341\,(250T_0)$

200 mb $T_0 = -\ 464.99 + 0.78515\,(200Z_0) - 0.78515\,(250Z_0) - 0.78136\,(250T_0)$

9.* Page 105. Substitute revised portion of table provided.

*Result of machine error.

The revised material on this and the following page may be cut out and pasted over the original printing.



Revised Fig. 4-1(d).
Cut out and paste onto page 17.

Revised portion of table. →
Cut out and paste onto page 105.

$250Z_0$	$300Z_0$, $300T_0$	833	39.6 ft	22.4 ft	831.3 ft	820.9 ft	28.7 ft	18.2 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	833	1.18°C	1.5°C	4.78°C	4.4°C	1.4°C	1.1°C
$200Z_0$	$250Z_0$, $250T_0$	833	57.2 ft	39.5 ft	764.8 ft	729.6 ft	32.5 ft	30.8 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	833	1.57°C	2.2°C	6.62°C	6.8°C	1.5°C	2.0°C

Revised Fig. 4-5 is on the following page.
Cut out and paste onto page 21.

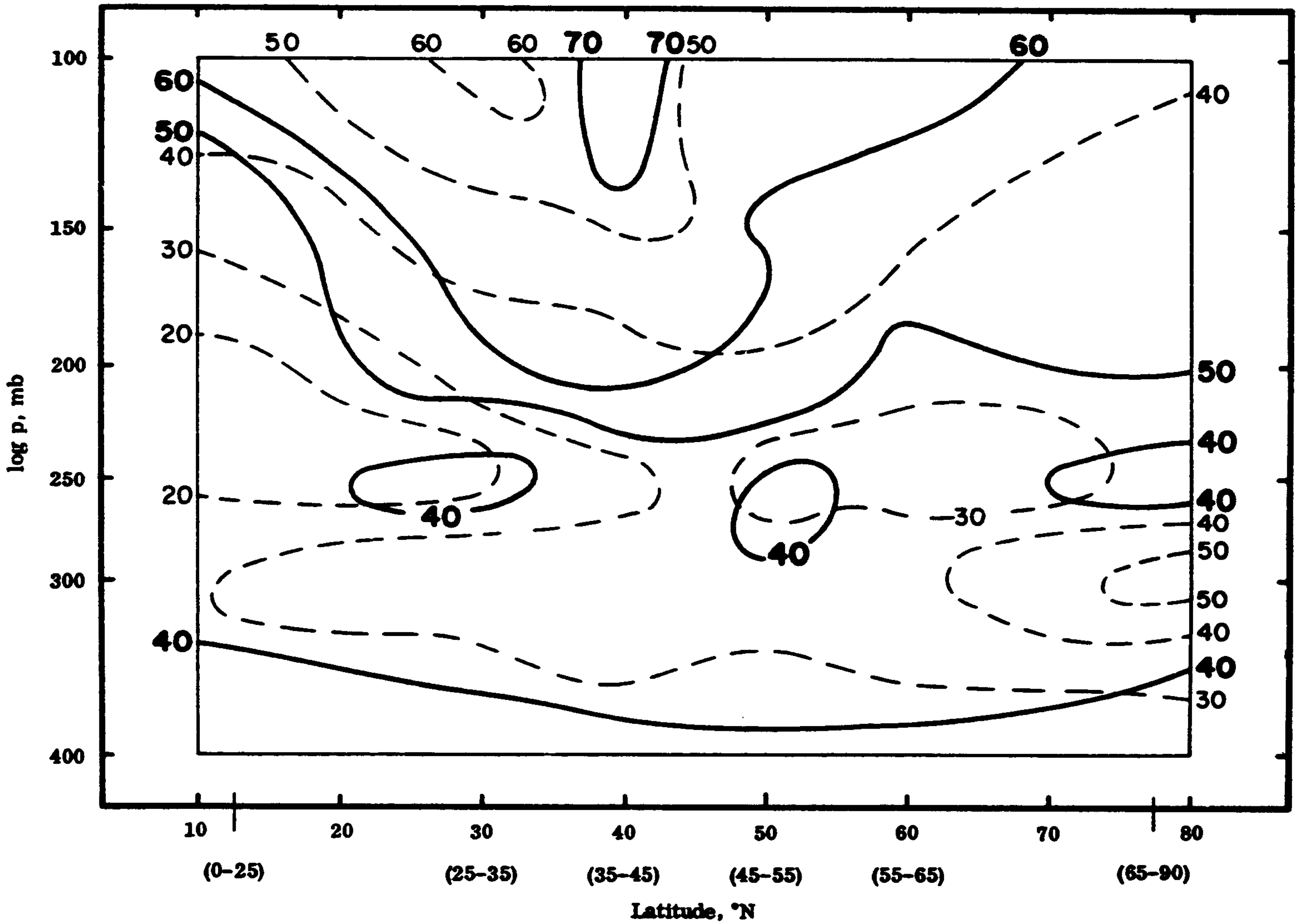


Fig. 4-5. Dependent and independent data results with TRC vertical-extrapolation regression equations for height for January.

ABSTRACT

Vertical-extrapolation regression equations for use in specifying initial-guess fields for objective analyses at 100 mb were derived (for four midseason months) through use of a screening procedure. Tests of the equations on independent data proved the equations to be stable, and the results for mid-season months are considered excellent. Further tests of the equations on data from one month on each side of each midseason month indicated that approximately 95% of the equations are useful and stable for the "side" months.

An experiment comparing the regression equations derived here with similar equations developed by the Navy in the 200–100-mb extrapolation interval illustrates that the newly derived equations yield significantly lower root-mean-square errors than the Navy equations.

A build-up analysis procedure incorporating the vertical extrapolation equations is described, and the results of limited development testing of the analysis procedure are discussed.

Results of an experiment that compared analyses employing initial guesses given by 12-hr persistence with analyses employing the build-up procedure indicated that the build-up produces significantly lower root-mean-square errors.

TABLE OF CONTENTS

1.0 INTRODUCTION

Objective analysis of temperatures, heights, and winds at stratospheric constant-pressure surfaces is a complex problem because of relatively sparse data coverage and increased instrumental and radiation errors in the available data [1, 12]. Obviously, a good initial guess is essential to any numerical objective analysis at stratospheric levels because over the no-data and sparse-data areas the "analysis" will effectively be the initial guess. Persistence has been suggested [6] as an initial guess, but it is not adequate over oceans and other sparse-data regions in which previous analyses are also questionable because of lack of data. The major aim here, therefore, has been directed toward generating the best possible initial-guess fields for height, temperature, and winds for 100-, 50-, and 30-mb objective analyses over the hemisphere.

Recently, Teweles and Snidero discussed some of the problems involved in objectively analyzing stratospheric constant-pressure surfaces. Their paper [13] describes a statistical build-up of a pattern from a 200-mb analysis to 100 mb, using vertical-extrapolation regression equations developed by the Navy [4]. The Navy equations use only the height and temperature at 200 mb for extrapolation to 100 mb. Regression equations were developed by the Navy for extrapolation of height and temperature through four other intervals: 200 to 50 mb, 100 to 50 mb, 100 to 30 mb, and 50 to 30 mb. In each case, the height and temperature of the lower level were the only predictors found to be useful. Several parameters were tested as possible secondary predictors. These parameters were various combinations of squares and products of temperature and height at the base of the extrapolation interval and the next lower level, and the difference between the temperature at the extrapolation base and the temperature at the next lower level. It was found that the inclusion of these did not significantly improve the basic regression equations.

One possible reason that the secondary predictors selected did not improve the results over the basic regression equations is that the coefficients for the primary predictors were held <u>constant</u>. Some improvement might have been gained had additional secondary predictors that incorporate past information been used (e.g., the past 12-hr thickness of the layer between the constant-pressure surface being "predicted" and the next lower constant-pressure surface).

Tests of the Navy's equations on independent data showed that the best results were obtained in the shorter extrapolation intervals (100 to 50 mb and 50 to 30 mb), and we use these equations for specifying initial-guess fields for height and temperature at 50 and 30 mb. The equations did not, however, yield results as satisfactory in the longer extrapolation intervals (200 to 100 mb, 200 to 50 mb, and 100 to 30 mb).

The hypothesis to be tested here is that the systematic incorporation of information contained in present and recent-past observations at mid- and upper-tropospheric levels (as well as that contained in stratospheric observations) will yield both a first-guess field and an analysis at stratospheric levels which are significantly superior to analyses incorporating only information contained in stratospheric observations of the present and recent past.

The analysis technique applied to the initial-guess fields is a modification of the technique described by Cressman [2]. Limited developmental testing of the analysis technique was performed to determine near-optimum values for the variables used in the analysis.

2.0 METHODS FOR COMPUTATION AND ANALYSIS

2.1 Vertical-extrapolation Screening-regression Experiments

A program that derives multiple linear-regression equations through the use of a screening procedure has been written by Enger and Rodante [3]. The screening procedure selects, from a set of possible predictors, a subset that contributes significantly and independently to reducing the variance of the predictand. The predictor having the highest linear correlation with the specified predictand is selected from an array of possible predictors. Next, the partial correlation coefficients between each of the remaining predictors and the predictand (holding the first predictor constant) are examined, and the predictor associated with the highest coefficient is then selected as the second predictor. Additional predictors are selected in a similar manner. This procedure is repeated until a chosen predictor fails to explain a significant additional percentage of the remaining variance of the predictand or until a specified maximum number of predictors is selected. The criterion of significance employed is a modified F-test described by Miller [5].

Table 2-1 is a list of the predictands and their respective possible predictors. In the table, the 300-mb height and temperature each appear twice as predictands to determine whether it is necessary to analyze the 400-mb level to obtain a good initial guess in the build-up to 300 mb. If the dependent-data root-mean-square error (RMSE) in extrapolating from 500 to 300 mb is "sufficiently less" (arbitrarily determined) than the combined error in extrapolating from 500 to 400 mb, and from 400 to 300 mb, then one could extrapolate from 500 to 300 mb without sacrificing the accuracy of the analysis build-up.

The screening-regression experiments were carried out (on an IBM 7090 computer at United Aircraft Corporation Research Laboratories in East Hartford) using radiosonde data from historical Northern Hemisphere data tapes for four midseason months: July and October 1958 and January and April 1959. The data were stratified into six latitude bands. Appendix A lists the stations used in each of the latitude bands.

TABLE 2-1
LIST OF "PREDICTANDS" AND POSSIBLE PREDICTORS USED IN VERTICAL-EXTRAPOLATION SCREENING-REGRESSION EXPERIMENTS*

Predictand	Possible predictors
$400Z_0$	$400Z_{-12}$, $500\text{-}400H_{-12}$, $500Z_0$, $500T_0$
$400T_0$	$400T_{-12}$, $500\text{-}400T_{m,-12}$, $500Z_0$, $500T_0$, $500\text{-}400H_0$
$300Z_0$	$300Z_{-12}$, $500\text{-}300H_{-12}$, $500Z_0$, $500T_0$
$300Z_0$	$300Z_{-12}$, $400\text{-}300H_{-12}$, $400Z_0$, $400T_0$
$300T_0$	$300T_{-12}$, $500\text{-}300T_{m,-12}$, $500Z_0$, $500T_0$, $500\text{-}300H_0$
$300T_0$	$300T_{-12}$, $400\text{-}300T_{m,-12}$, $400Z_0$, $400T_0$, $400\text{-}300H_0$
$250Z_0$	$250Z_{-12}$, $300\text{-}250H_{-12}$, $300Z_0$, $300T_0$
$250T_0$	$250T_{-12}$, $300\text{-}250T_{m,-12}$, $300Z_0$, $300T_0$, $300\text{-}250H_0$
$200Z_0$	$200Z_{-12}$, $250\text{-}200H_{-12}$, $250Z_0$, $250T_0$
$200T_0$	$200T_{-12}$, $250\text{-}200T_{m,-12}$, $250Z_0$, $250T_0$, $250\text{-}200H_0$
$150Z_0$	$150Z_{-12}$, $200\text{-}150H_{-12}$, $200Z_0$, $200T_0$
$150T_0$	$150T_{-12}$, $200\text{-}150T_{m,-12}$, $200Z_0$, $200T_0$, $200\text{-}150H_0$
$100Z_0$	$100Z_{-12}$, $150\text{-}100H_{-12}$, $150Z_0$, $150T_0$
$100T_0$	$100T_{-12}$, $150\text{-}100T_{m,-12}$, $150Z_0$, $150T_0$, $150\text{-}100H_0$

*H, T, and Z are thickness (ft) of layer between constant-pressure surfaces, temperature (°C) at constant-pressure surface, and height (ft) of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

The regression program allows for several predictands and their predictors to be specified at one time by generating a large covariance matrix comprising all predictands and predictors. An interchange of designation of variables as predictors or predictands for different experiments is also possible with the generation of the large matrix. The ability to determine several regression equations with one machine run results in a marked saving of computer time over deriving each equation in separate runs.

The variability of times at which a station reports during the month and the variability in the termination level of the sounding (when there is a sounding) made a preprocessing program necessary for the selection of cases for the predictands [11]. The 14 predictands listed in Table 2-1 are separated into three groups of six, four, and four (reading from top to bottom) for all stations. If a station is to be selected as a case for the screening program, it <u>must</u> report all parameters in its group (predictors and predictands); if even one is missing, that station is not selected. The number of cases for each group and each latitude band is determined for the month in question. The procedure sometimes excludes a few cases that would be included werc individual matrices generated for each predictand, but the advantage in saved computer time far outweighs the loss of the few cases.

At the other extreme, a matrix for all 14 predictands and their respective predictors could be generated--and would yield a further saving of computer time. This, however, would require that all 14 predictands and their predictors be reported and would result in the loss of stations whose soundings "topped off" below 100 mb--as many as 118 cases in a latitude band. Obviously, this would be unsatisfactory. The breakdown into the groups of six, four, and four provides the most feasible solution to the problem of selecting enough cases while minimizing computer time.

2.2 Analysis Procedure, 500-100 mb

The initial guess for the 500-mb height analysis is the previous 12-hr 500-mb height analysis. For operational purposes, it is suggested that the initial-height guess at 500 mb be a 12-hr dynamical prognostic chart valid for analysis time. The initial guess for the temperature field at 500 mb is the previous 12-hr temperature analysis. Once again, operationally, if a 12-hr dynamical temperature prognostic chart is available, it should be used as the initial guess.

Station observations of 500-mb heights and winds at analysis time are used successively to "correct" the initial-guess field heights, using a technique very similar to that in use at the Numerical Weather Prediction (NWP) Unit of the National Meteorological Center (NMC) and outlined by Cressman [2]. Essentially, the technique is the following.

In a given scan through the data, a "correction" is computed for each gridpoint within a specified radius R of any reporting station. A weighting factor is computed for each station as a function of the distance between the gridpoint being corrected and the station. The reported wind direction and speed are used in conjunction with the heights to help establish the gradient of the height contours. [The procedure will be referred to here as the successive-approximation technique (SAT).] The "correction" equation [Eq. (2-1), below] allows for the station observation to be weighted relative to the initial guess at the gridpoint as well as to the winds, and hence represents a change in the equation used at the NWP Unit.

$$C = W(d)\left[\frac{Z_{x,y} + nZ_{obs}}{1 + n} + \frac{mkfv_0}{g}x' - \frac{mkfu_0}{g}y' - S(x_s, y_s)\right]. \qquad (2\text{-}1)$$

Here, W(d) is the distance-weighting function; $Z_{x,y}$ is the initial-guess value of height at the gridpoint being corrected; Z_{obs} is the observed height at the station; n is the weighting factor of the station observation to the initial guess at the gridpoint; m is a map-scale factor; k represents the average ratio of the geostrophic

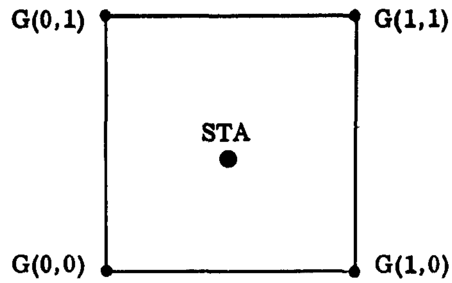


Fig. 2-1. Schematic representation of gridpoints used in curvilinear interpolation.

to the actual wind and is set at 1.08 (the value suggested in Cressman's paper [2]; g is the acceleration of gravity; u_0 and v_0 are the components of the wind along the i- (horizontal) and j- (vertical) directions of the grid, respectively; x' and y' are the distances in grid units in the i- and j-directions, respectively, with the origin taken at the reporting station; and $S(x_s, y_s)$ is obtained by fitting a curvilinear surface exactly to the initial-guess values $G(x,y)$ at the four gridpoints surrounding the observation station.

The equation for a curvilinear surface is given by

$$S = a + bx + cy + dxy, \tag{2-2}$$

where x and y are distances in units of grid intervals in the i- and j-directions on the NWP grid, and

$$a = G(0,0),$$
$$b = G(1,0) - G(0,0),$$
$$c = G(0,1) - G(0,0),$$
$$d = G(1,1) - G(0,1) - G(1,0) + G(0,0),$$

where the G's are as indicated in Fig. 2-1. The total "correction" applied to a gridpoint is simply the mean of the corrections computed during a given pass through the data.

The temperature analysis also uses SAT in arriving at a final field of temperature at gridpoints. For temperature, the correction equation is

$$C = W(d)\ [T_s - S(x_s, y_s)], \qquad (2\text{-}3)$$

where W(d) and $S(x_s, y_s)$ are as in Eq. (2-1), and T_s is the observed value at the station.

The 500-mb height and temperature fields thus analyzed form the base for extrapolating to successively higher levels.

For analysis of height and temperature at the next-higher level (400 or 300 mb) the heights are specified first, using the results of the screening-regression experiments. The specified 400- (or 300-) mb height field is the initial guess for the 400- (or 300-) mb analyses to be carried out in the same manner as that described above for the 500-mb height analysis. It appears that analyzing heights before temperatures at the next-higher level is more useful than analyzing temperatures first because the winds aid in arriving at a height analysis, and the resulting height analysis may then be used to compute a current thickness field. This field, in turn, is very likely to be helpful in obtaining a more accurate temperature analysis.

From 400 (or 300) mb, the analysis proceeds to 100 mb in steps of 50 mb (but bypassing 350), with the height analysis being performed first and the temperature analysis second. The results of the regression experiments supply the initial guess at the next-higher level for the heights and temperatures at gridpoints.

Beginning at 100 mb, solar radiation errors become important. The 100-mb height and temperature data used in the analysis are corrected for radiation effects. The corrections are based on the work of the Stratosphere Project of the U.S. Weather Bureau under the direction of S. Teweles [12].

For the wind analyses, gradient winds are computed from the height field at every level and are used as an initial guess to a direct wind analysis using SAT. Winds are resolved into u- (east-west) and v- (north-south) components for the purposes of analysis, but the capability for printing wind direction and wind speed from the final passes of the u- and v-component analyses is included in the analysis program.

2.3 Analysis Procedure, 100–30 mb

From 100 mb, the Navy vertical-extrapolation regression equation is used to obtain the initial guesses of height and temperature at 50 mb. These 50-mb fields are analyzed in the same manner as that described in Section 2.2 (SAT) for the other constant-pressure surfaces. The 50-mb analyses are extrapolated to 30 mb through use of the 50–30-mb Navy extrapolation coefficients for height and temperature, and the 30-mb analyses use SAT. The radiosonde data at 50 and 30 mb are corrected for radiation errors as discussed above for the 100-mb data. As before, gradient winds are computed from the height analyses and are used as initial guesses to direct wind analyses.

3.0 EXPERIMENTS AND EVALUATION PROCEDURES

3.1 Evaluation of Vertical-extrapolation Regression Equations, with Dependent and Independent Data

The regression equations developed for the four midseason months by the program discussed in Section 2.1 were tested on independent data. (Radiation corrections were applied to the dependent and independent 100-mb data where necessary.) The independent data were selected from radiosonde observations in the historical Northern Hemisphere data books only from midseason months of years not included in the developmental data sample. Among the independent data were stations not included in the original dependent sample. This allowed the data to be as truly independent as possible with respect to both time and geography within a latitude band. Fifty cases were chosen as independent data for each of the six latitude bands for each of the four midseason months.

The equations were tested on independent data for the months for which they were developed. They were also tested on data from the months on each side of the midseason months to determine whether they were stable and useful for those months as well.

3.2 Comparison of TRC Equations and Navy Equations

As suggested in Section 1.0, it has been our belief that the Navy vertical-extrapolation regression equations could be improved with the use of additional predictors. An experiment was performed to test this hypothesis.

In the experiment, a 200–100-mb height regression-extrapolation equation was derived for the 25–35° latitude band. This extrapolation interval and this latitude band were selected for two reasons: (a) the 200–100-mb is the only extrapolation interval directly comparable to the intervals for which we are deriving equations, and (b) the tropopause is most likely located in the 200–100-mb layer in January, in the 25–35° latitude band, and it is through the tropopause region that the "prediction" of heights is most difficult. At higher latitudes, the tropopause is, of course, usually found at a layer lower than the 200–100-mb layer.

The possible "predictors" specified for the TRC equation are $200Z_0$, $200T_0$, $200-150H_{-12}$, $150-100H_{-12}$, and $100Z_{-12}$. (The symbols and subscripts are identical to those in Table 2-1.) The Navy regression coefficients were available for the 20–30° and 30–40° latitude bands, using as "predictors" $200Z_0$ and $200T_0$.

Both equations were tested on the same independent data (100 cases) for the 25–35° latitude band. It was necessary when using the Navy equation to use two sets of coefficients, one for the stations in the 20–30° latitude band and the other for stations in the 30–40° latitude band. The TRC equation used one set of coefficients derived for 25–35° latitude band.

3.3 Comparison of Objective and Subjective Wind Analyses at 100 mb

Before electronic computers became available, constant-pressure charts were necessarily drawn by hand. It is natural, therefore, to compare an objective analysis with a conventional, subjective hand analysis made from the same data.

For this comparison, objective analyses of wind at 100 mb were performed with gradient winds computed from height analyses as initial guesses for three observation times in January 1959. The direct wind analysis was carried out by SAT, with the actual wind observations. A percentage of the observations was withheld from the analysis for verification purposes. The subjective hand analyses were drawn from the same data used to verify both kinds of analysis.

In determining an analysis value at a withheld station, a curvilinear surface [Eq. (2-2)] was fitted exactly to the values at the four gridpoints surrounding the station. It was necessary, for analysis and verification purposes, to separate the wind into its two components, u and v. (In this particular case, u and v are with respect to the i- and j-directions, respectively, of the NWP grid.)

3.4 Developmental Testing of the Objective Analyses, and Verification by the Areal-mean-error Method

In the objective analysis procedure, several parameters may be varied during any given analysis (e.g., the influence radius R from a gridpoint, and the weighting factor n, which weights the station observation of height relative both to the initial guess at a gridpoint and to the winds). Developmental testing consists in assigning several values to these parameters and determining those that will minimize the analysis errors. The analyses are verified by the areal-mean-error method [14]. This method approximates an area integral of the error over the analysis area by withholding some percentage of the observations and verifying back to the "withheld"- and "analysis"-station observations, which are equally weighted.

The areal root-mean-square error (ARMSE) is given by

$$\text{ARMSE} = \left[\frac{\sum_w (\Phi_w - s)^2 \rho_w^{-1}}{2\sum_w \rho_w^{-1}} + \frac{\sum_a (\Phi_a - s)^2 \rho_a^{-1}}{2\sum_a \rho_a^{-1}} \right]^{1/2} \tag{3-1}$$

where the subscript w refers to quantities at the location of observations <u>not</u> used in the analysis computations (i.e., the withheld-station observations), Φ is an observed value, s is an analysis value obtained by fitting a curvilinear surface exactly to the values at the four gridpoints surrounding the observing station, and ρ is the density of analysis stations in the region about a station. Analysis stations are defined as stations <u>used</u> in the analysis computations, and quantities pertaining to them are denoted by a subscript a.

The withheld-station observations approximate the maximum-error points in the analysis field, but the number of withheld stations required by the areal-mean-error method does not usually equal the number of maximum-error points in the analysis-error field. Therefore, the withheld stations must be selected in a manner that will allow them to represent equally the entire spectrum of maximum errors over the analysis area. The assumption here is that the maximum error is inversely proportional to the density of the data. For the purpose of developmental tests, in which a series of maps is analyzed in one computer run, it is advisable to use a permanent set of withheld stations to obtain an unbiased sampling of the maximum errors [14].

To choose the permanent set of withheld stations, a measure of station density was computed for each observation for a series of 20 observation times. The stations were then ranked in order of increasing density, and the ranked set of stations was divided into groups of K stations each. One station was selected from each group on the basis of the frequency with which it reported during the series. The station that reported most frequently throughout the series was usually selected, provided that it was not in the immediate area of some previously selected station. If it was, then the station that reported next most frequently was chosen.

Most of the developmental testing was done on a North American grid. Limited testing was done on a hemispheric grid.

3.5 Comparison of "Build-up" and Persistence as Initial Guess to 100-mb Analyses

Our major aim of specifying the best possible initial guesses for analyses at 100 mb required that our procedure for build-up analysis (see Section 2.2) be compared with persistence. Our procedure uses vertical-extrapolation regression equations to generate initial guesses in steps to 100 mb. An experiment was conducted to evaluate the relative accuracy of 100-mb temperature and wind analyses using, on the one hand, 12-hr persistence as a first guess and, on the other, the build-up first-guess field. In this experiment, a series of maps was analyzed for five consecutive upper-air observation times. The initial analysis time was 1200Z January 1, 1959. Identical sets of analysis and verification observations were used for the analysis for each type of first-guess field. The analysis area for this experiment was the North American grid, as illustrated in Fig. 4-10. The results of the experiment are given in Section 4.0.

4.0 RESULTS OF EXPERIMENTS

4.1 Evaluation of Vertical-extrapolation Regression Equations, with Dependent and Independent Data

4.1.1 Midseason Months

After each predictor had been selected according to the screening procedure described in Section 2.1, the appropriate regression equation was derived. This resulted in 1512 equations, (i.e., four equations for each height in each latitude band and month, and five equations for each temperature in each latitude band and month).

There remained the problem of selecting the most useful equation for each predictand. The criterion for selection in most cases was the modified F-test for significance of a "predictor," described by Miller [5]. It was subjectively decided to eliminate some of the "predictors"—even though the F-test showed them to be significant—whenever the developmental sample results indicated that there would be little to gain in the operational use of an additional predictor.

The question posed in Section 2.1 regarding the necessity of using one set of vertical-extrapolation equations from 500 to 400 mb and another set from 400 to 300 mb rather than one set of equations from 500 to 300 mb is answered by the dependent and independent data results. The results indicate that for July, the extrapolation from 500 to 300 mb may be performed without generating unacceptable errors in the analysis build-up (i.e., the largest 300-mb RMSEs among all latitude bands are 1.51°C for temperature and 66.9 ft for height). For other midseason months, it would profit the analysis to include the 400-mb level in the build-up procedure. If it is deemed necessary to extrapolate to 400 mb for one latitude band, the program makes it mandatory to extrapolate to 400 mb for all latitude bands. Hence, there are 312 vertical-extrapolation regression equations for the four midseason months for extrapolation from 500 to 100 mb. These equations, as well as the Navy equations for extrapolation from 100 to 30 mb, are given in Appendix B.

The results on dependent and independent data appear in graphical form in Figs. 4-1 through 4-8 and are presented in tabular form in Appendix C.

In general, the independent-data tests indicate that the equations are stable, for the independent errors are close to the values of the dependent data errors. The largest errors in temperature occur, as might be expected, in the layers in which the tropopause is frequently found. This is strikingly revealed in the January temperature graphs (Fig. 4-1), which show dependent-data temperature errors to be of the order of 2.5°C for the stations between latitudes 35 and 55° in the 250–200-mb layer. Synoptic experience agrees with these results, since the tropopause is often found in the 250–200-mb layer between latitudes 35 and 55° during January.

The graphical temperature results for July (Fig. 4-3) show that the largest errors in temperature are in the vicinity of the 150–100-mb layer for latitudes 0–45°N, where synoptic experience places the tropopause in the summer. The error curve for the 35–45° latitude band suggests that it is also often found in the 200–150-mb layer as well. In the more tropical portions of the 0–45° band, the tropopause is probably frequently above 100 mb, and the results indicated in Lea's paper [4] for the 100–50-mb temperature equations bear this out.

Although the errors are largest for the extrapolation intervals in which the tropopause is frequently located, they would be larger if past 12-hr information were not included as possible "predictors." This statement may be confirmed by examining the results of the comparative-accuracy test between the Navy and TRC equations (see Section 4.2). This test demonstrates that the inclusion of additional parameters significantly improves the earlier Navy equations. Further confirmation may be obtained in the tabular results appearing in Appendix C, which include a listing of the selected predictors (i.e., those predictors that are statistically significant as determined by the modified F-test mentioned in Section 4.1.1). It is seen that for the "more difficult" extrapolation intervals (those in which the tropopause is often found), the past thickness and past height

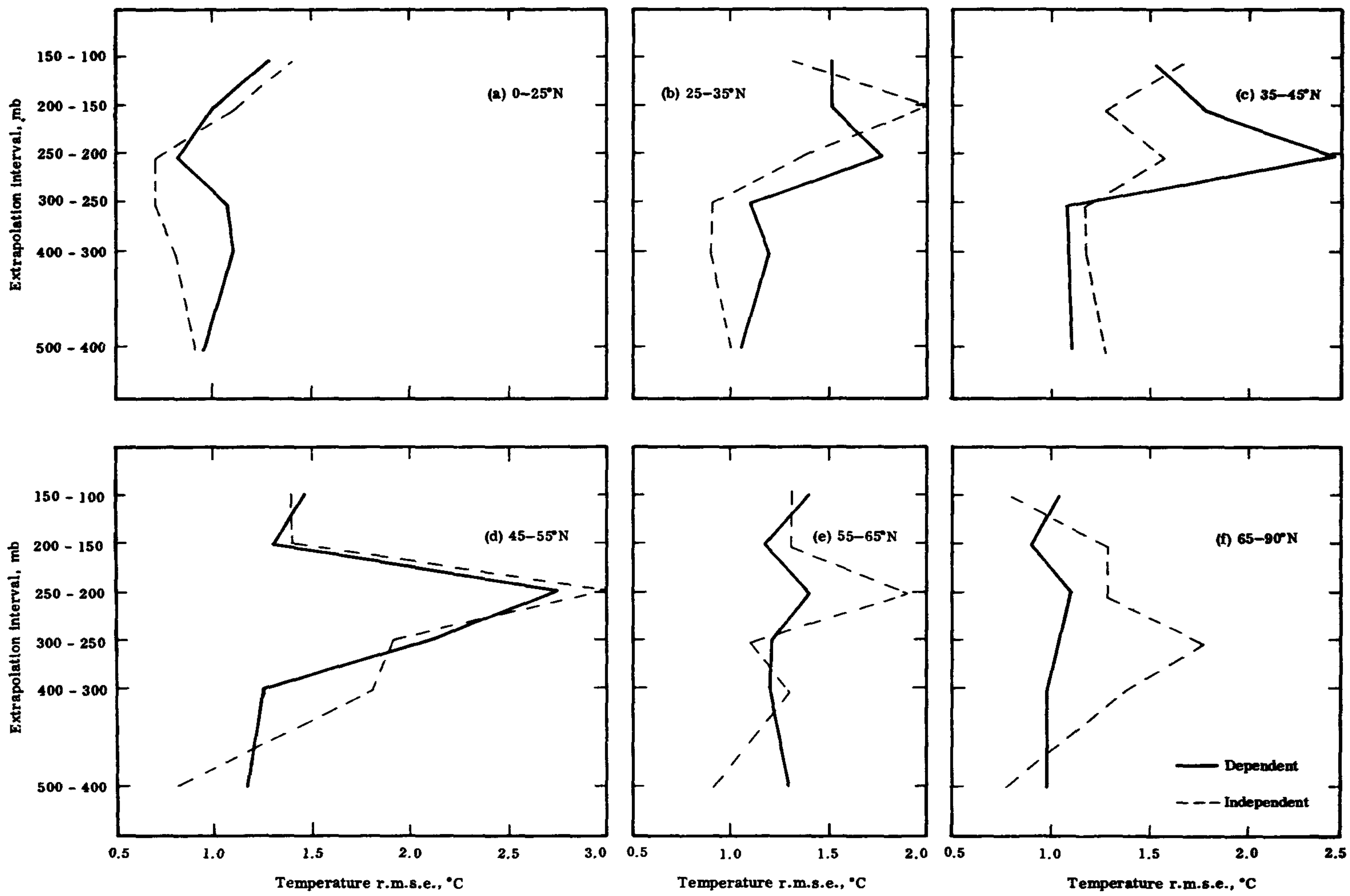


Fig. 4-1. Dependent and independent data results with TRC vertical-extrapolation regression equations for temperature for January for six latitude bands. (a) 0–25°N. (b) 25–35°N. (c) 35–45°N. (d) 45–55°N. (e) 55–65°N. (f) 65–90°N.

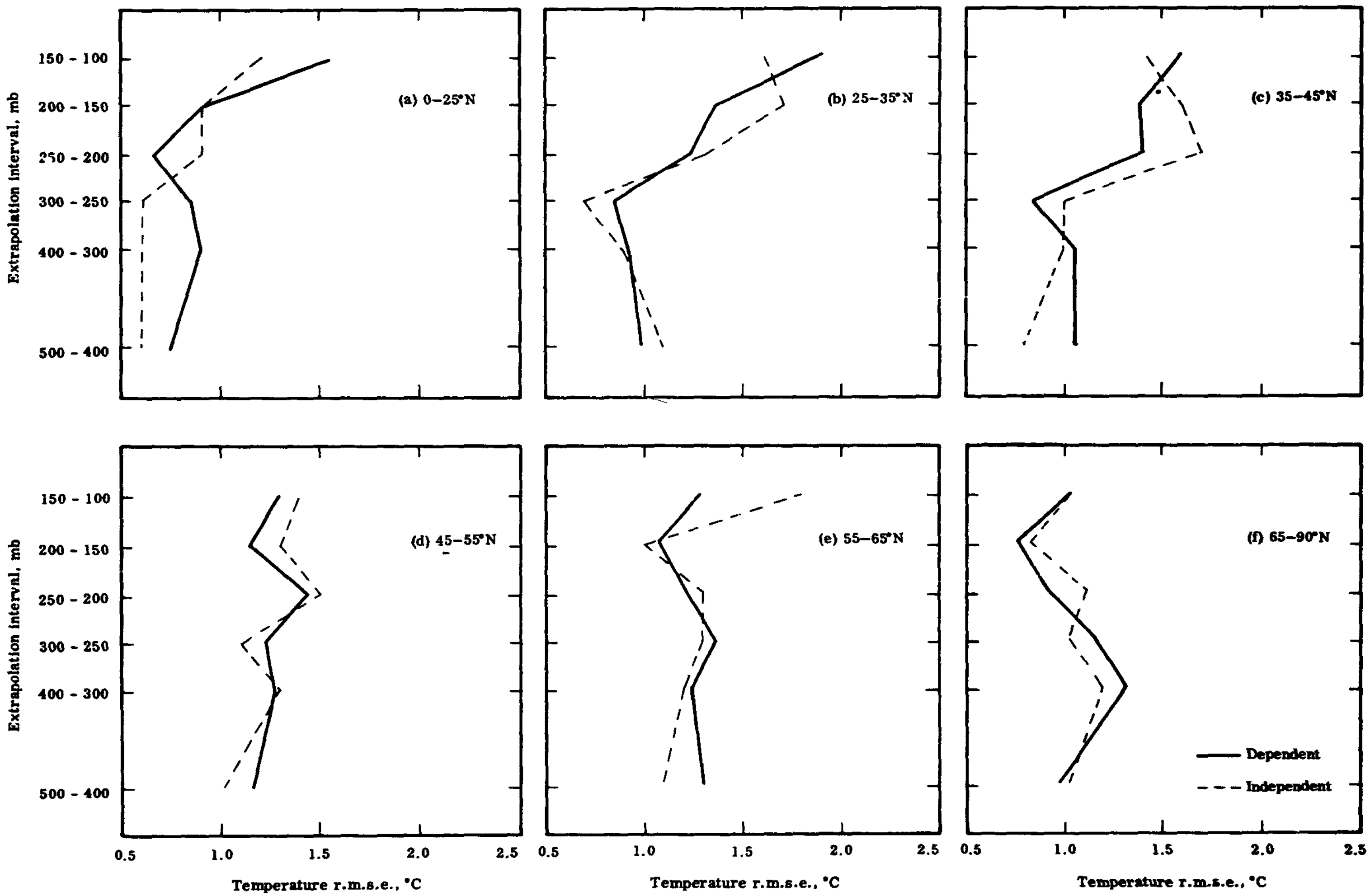


Fig. 4-2. Dependent and independent data results with TRC vertical-extrapolation regression equations for temperature for April for six latitude bands. (a) 0–25°N. (b) 25–35°N. (c) 35–45°N. (d) 45–55°N. (e) 55–65°N. (f) 65–90°N.

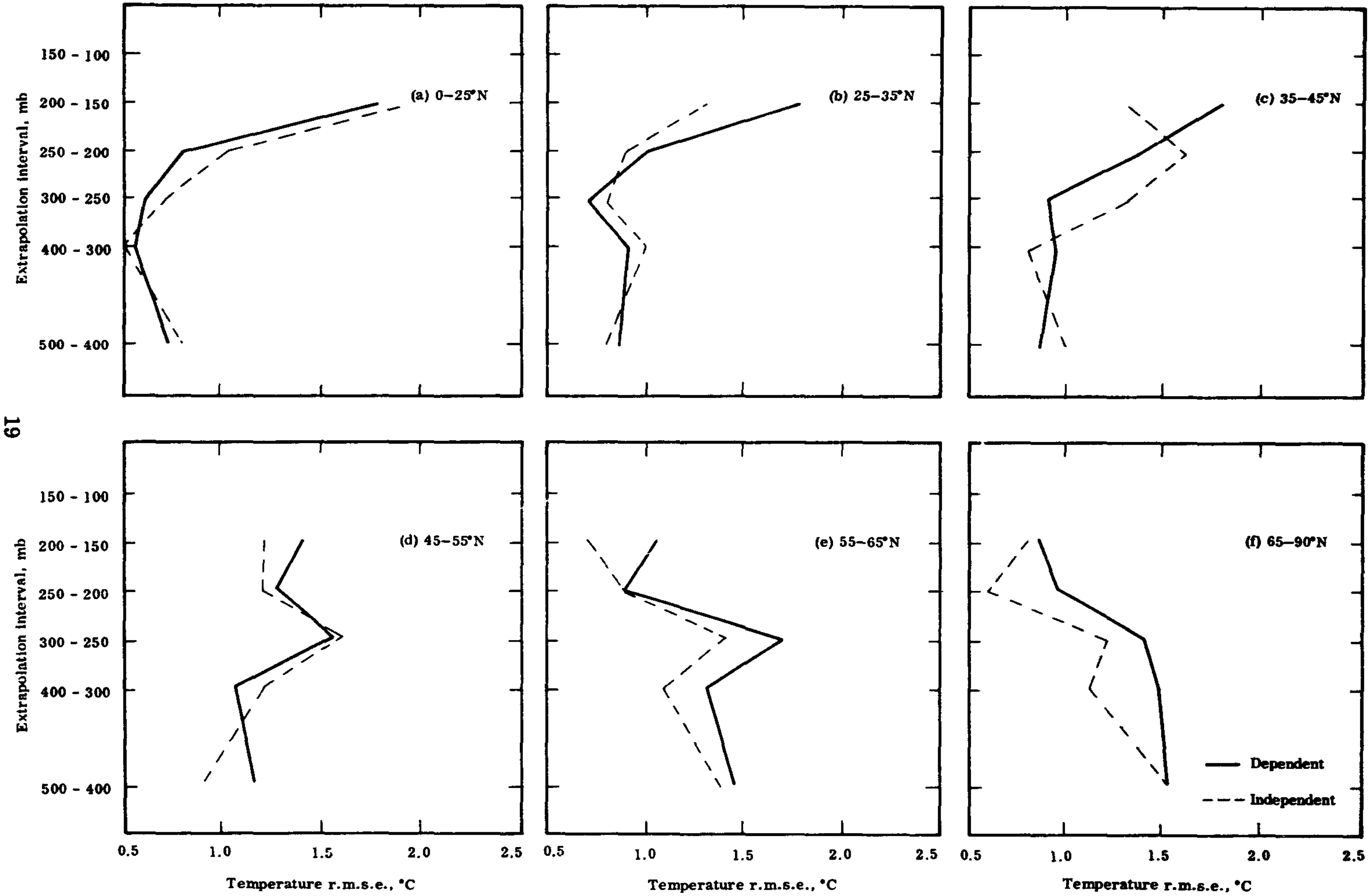


Fig. 4-3. Dependent and independent data results with TRC vertical-extrapolation regression equations for temperature for July for six latitude bands. (a) 0–25°N. (b) 25–35°N. (c) 35–45°N. (d) 45–55°N. (e) 55–65°N. (f) 65–90°N.

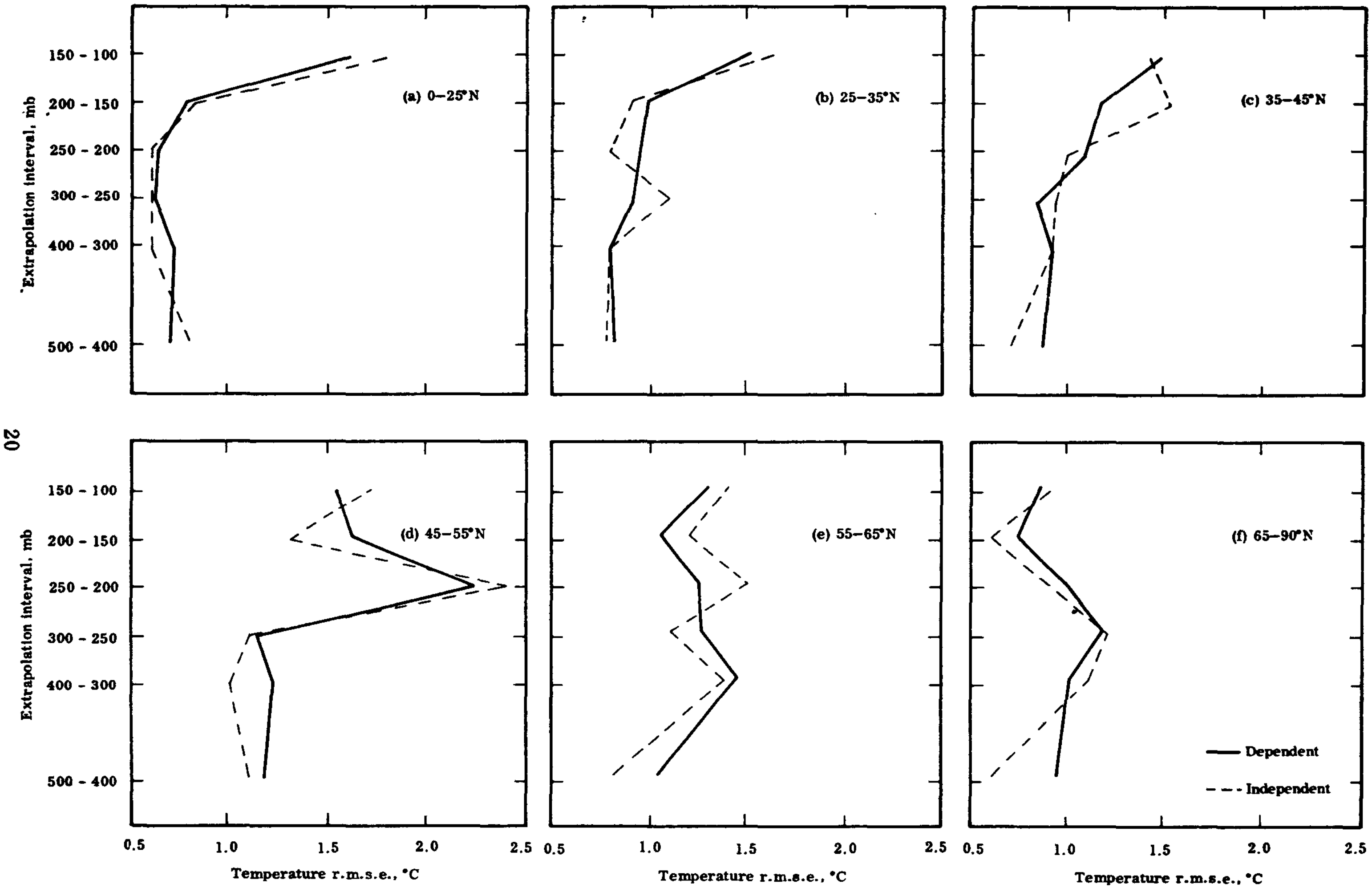


Fig. 4-4. Dependent and independent data results with TRC vertical-extrapolation regression equations for temperature for October for six latitude bands. (a) 0–25°N. (b) 25–35°N. (c) 35–45°N. (d) 45–55°N. (e) 55–65°N. (f) 65–90°N.

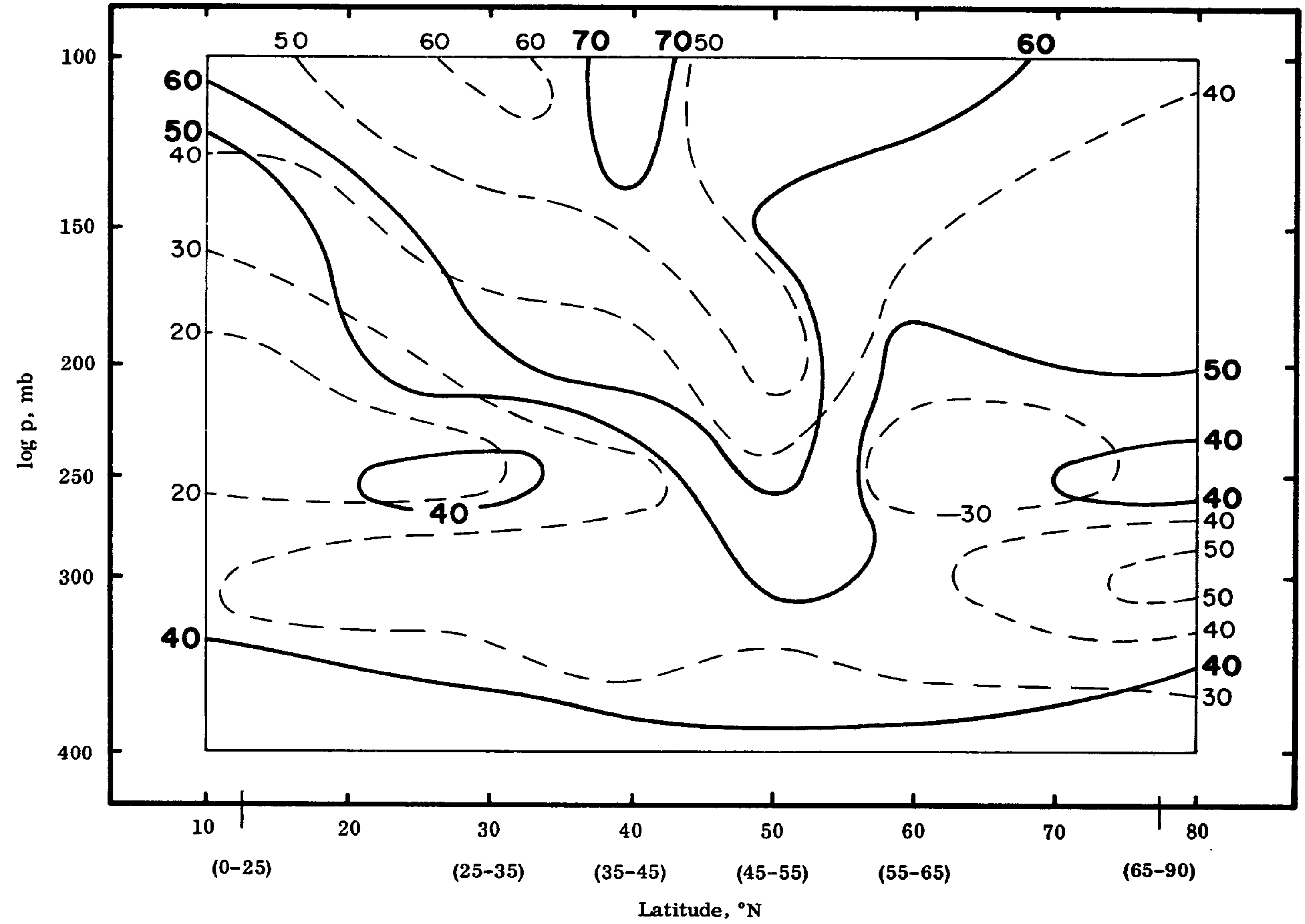


Fig. 4-5. Dependent and independent data results with TRC vertical-extrapolation regression equations for height for January.

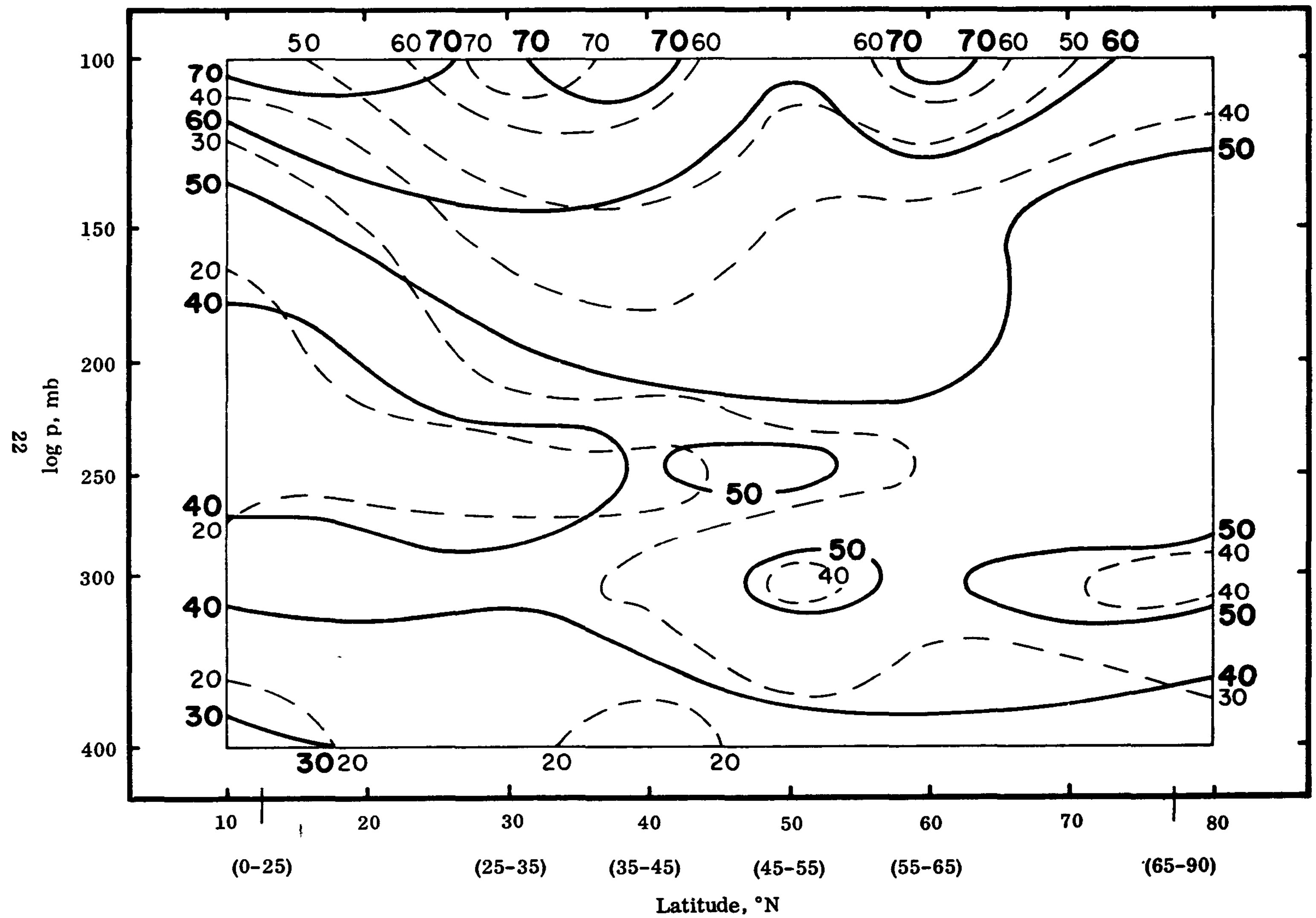


Fig. 4-6. Dependent and independent data results with TRC vertical-extrapolation regression equations for height for April.

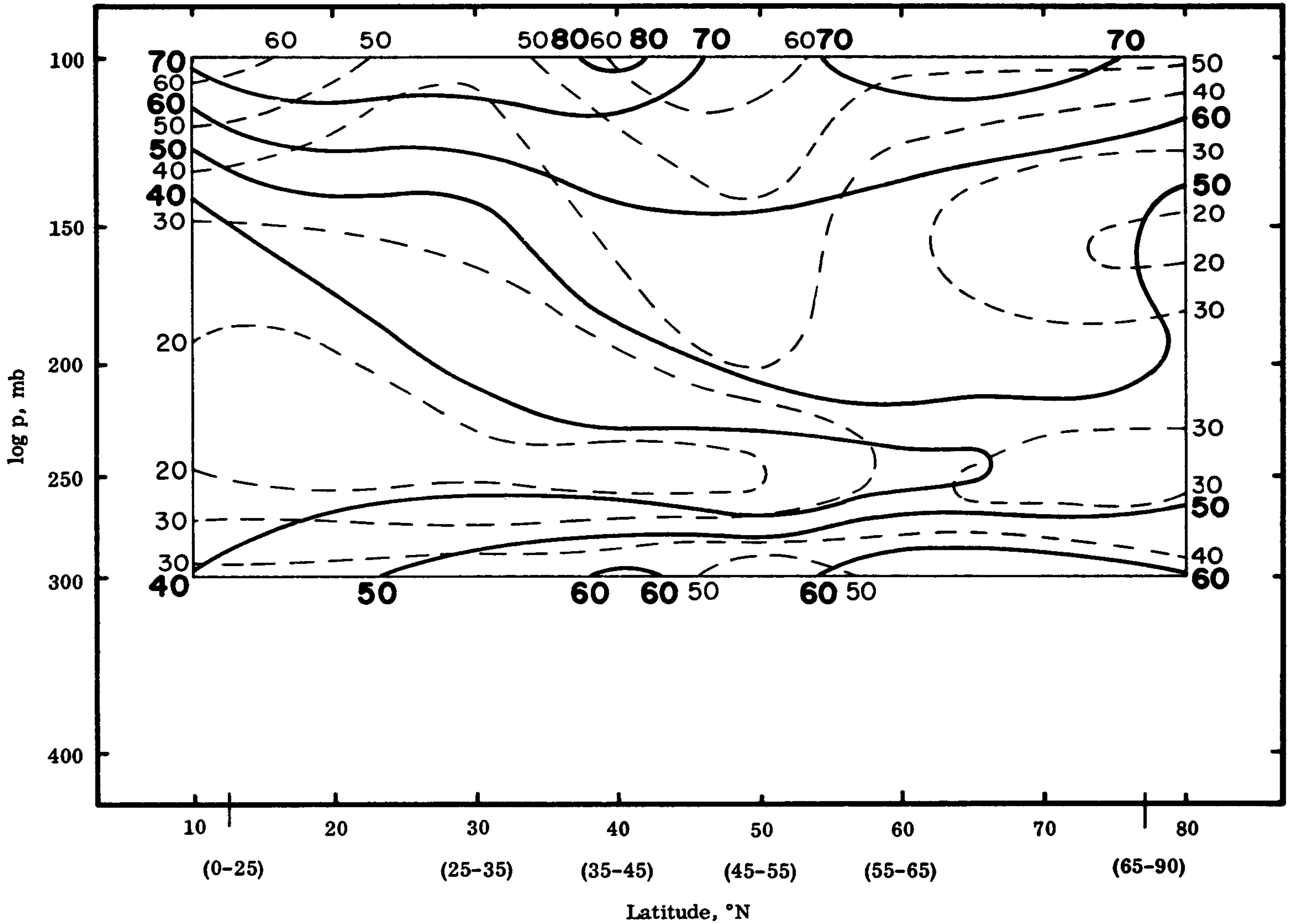


Fig. 4-7. Dependent and independent data results with TRC vertical-extrapolation regression equations for height for July.

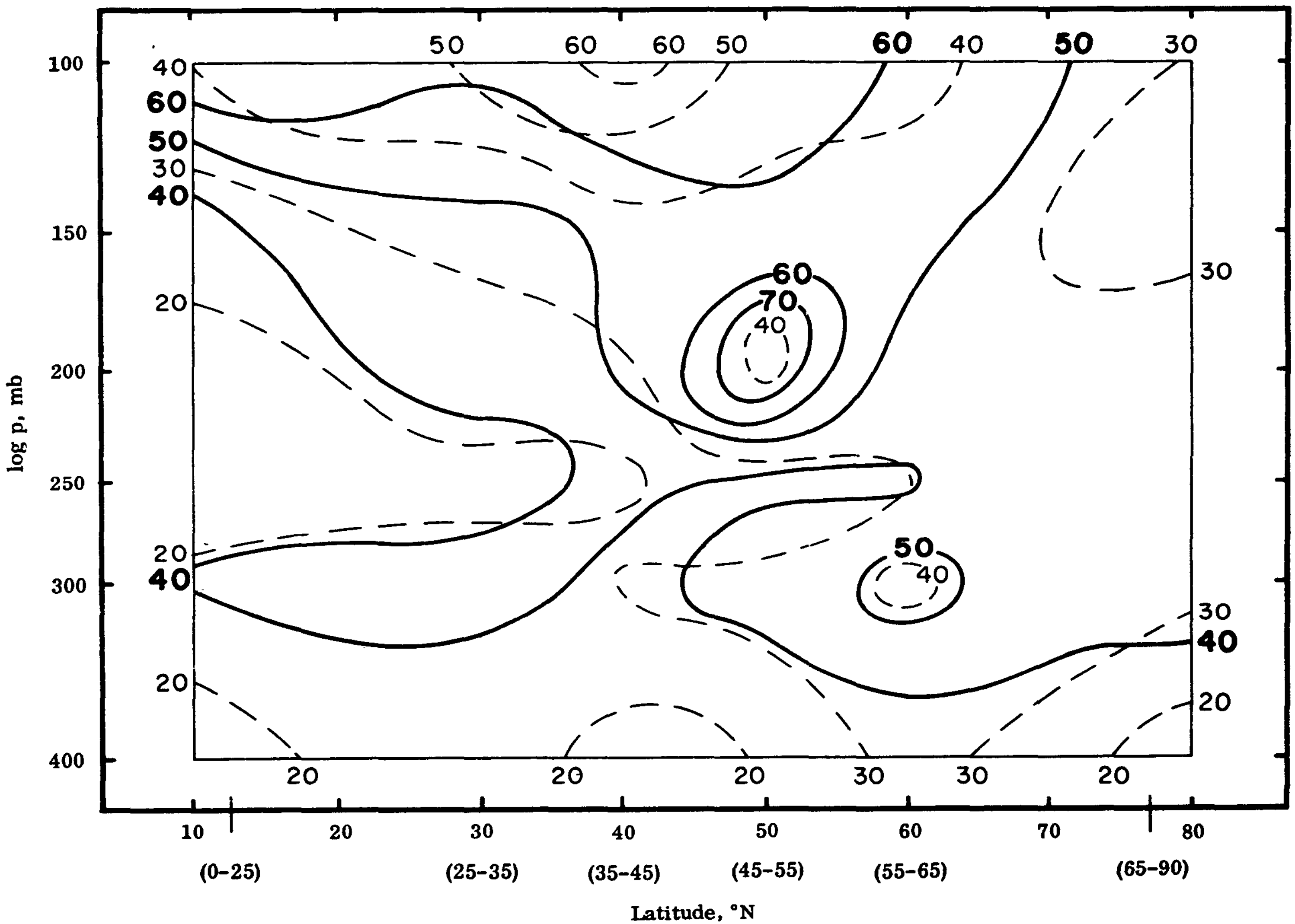


Fig. 4-8. Dependent and independent data results with TRC vertical-extrapolation regression equations for height for October

are selected for the height extrapolation, and the past temperature is found to be significant in specifying the temperature.

The graphs of the dependent- and independent-data RMSE for height (Figs. 4-5 through 4-8) indicate an apparent double maximum of errors, which is most noticeable on the January and October graphs.

The maximum in middle latitudes at the 200- and 250-mb levels may be explained by the frequent presence of the tropopause in those regions. The second area of large errors is at the 100-mb level and is not confined to one latitude band or month. Instead, a rather flat gradient of errors is evident across all latitude bands and most months because, despite the radiation corrections applied to the data at 100 mb, instrumental errors persist. These errors are of the order of 100 to 200 ft at 100 mb [1]. Temperature observations in the stratosphere, on the other hand, are considered to be accurate to within 1 or 2°C; hence a secondary maximum of errors across all latitude bands does not appear in the temperature results.

4.1.2 "Side" Months

The equations derived for the midseason months were tested on the month on each side of each midseason month to determine whether the equations were stable and useful for those months. Twenty-five cases were used for each "side" month for testing and evaluation. The independent-data RMSEs for the predictands appear in tabular form in Appendix C alongside the results for the midseason months.

The evaluation of the RMSEs for the "side" months revealed that in no case does it appear that new equations need be derived for an entire latitude band. Figure 4-9 depicts the "predictands" in each latitude band and month for which it appears that it is necessary to derive a new equation. It also shows 17 "predictands" whose RMSEs indicated that there was some question as to whether a new equation need be derived. Additional cases are necessary to determine the

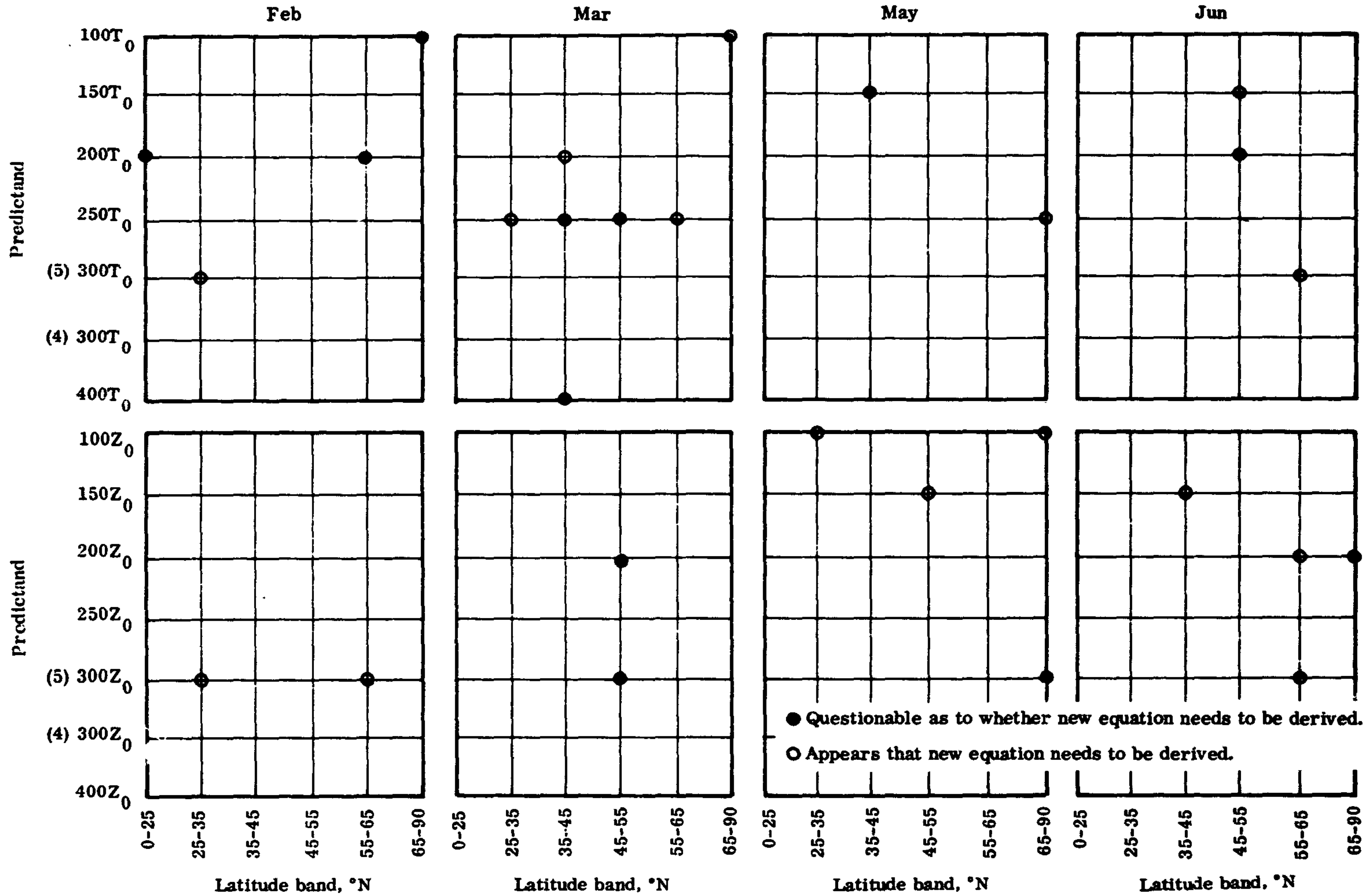


Fig. 4-9(a). Predictands for which new equations appear to be necessary.

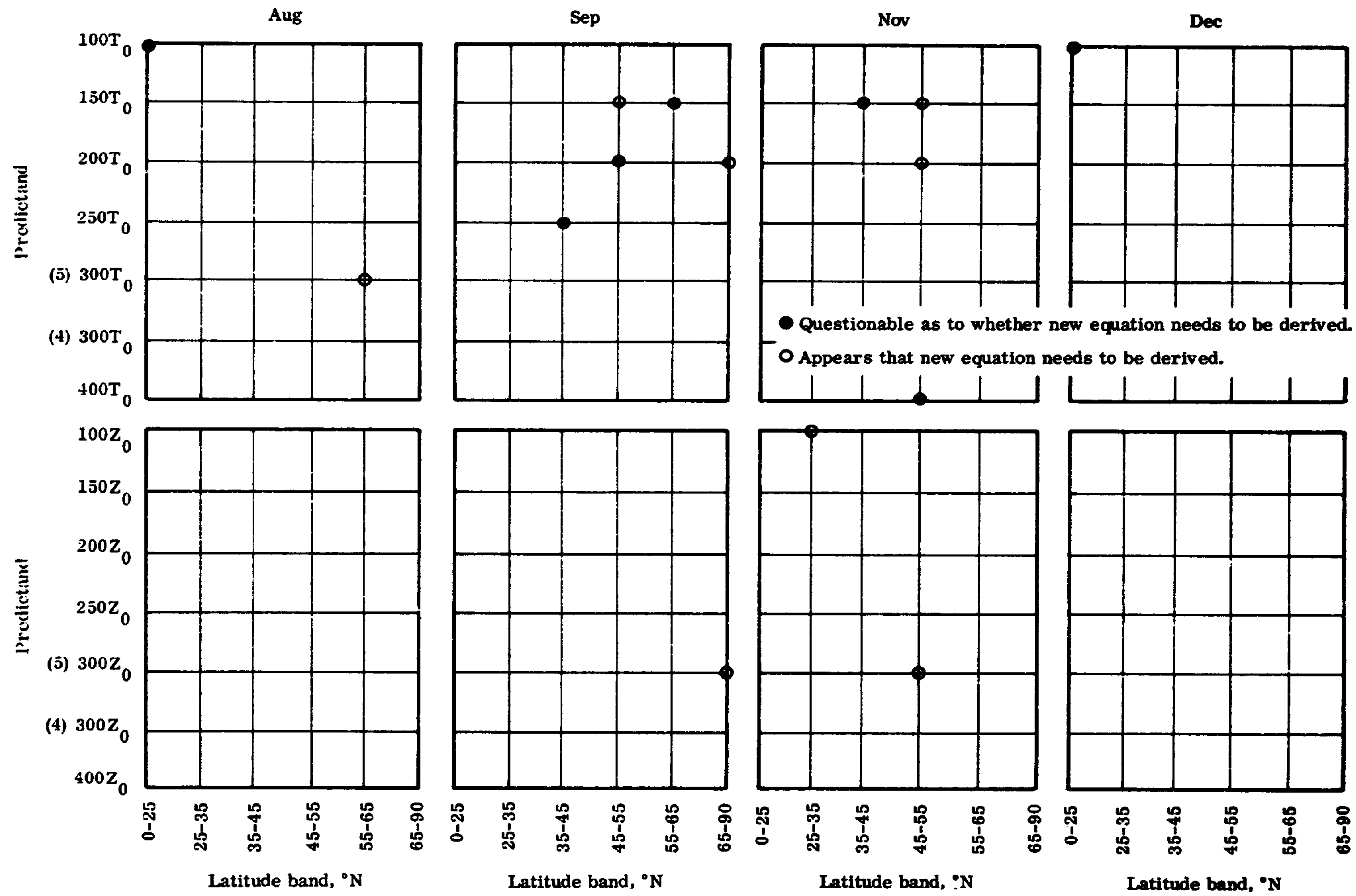


Fig. 4-9(b). Predictands for which new equations appear to be necessary.

percentage of these "questionable predictands" that will need new equations. Some further testing with a larger sample will be carried out for a portion of the "predictands" that appear to need new equations as well as for all of the "questionable predictands." In addition, it is planned to test on a larger sample some of the predictands whose RMSEs indicate that new equations are <u>not</u> necessary. These additional tests are aimed at more accurately determining the stability of the equations with the "side" months.

It is seen that there are 24 "predictands" for which new equations will probably be derived, of which 14 are for temperature and 10 are for height. Of the 10 probable new height equations, five are for the 500–300-mb extrapolation interval (which will not be used in the analysis build-up except during June, July, and August), but the five equations are expected to be used in a prediction technique that is based on the regression equations.

Inasmuch as each of 84 equations for each midseason month (except 60 for July) was tested on two months other than the midseason month for which it was developed, it was possible that 624 new equations would have had to be derived if the RMSEs proved too great. But it now seems necessary to derive only 20 to 40 new equations (about 5% of all that is "possible"), and this would indicate that the equations are apparently stable, for the most part, for a season. This is especially true of the January (winter) equations (Fig. 4-9), which were used on data from December and February. For December, there are no "predictands" that appear to need new equations, but one that is "questionable"; for February, there are only three needing new equations, and three that are "questionable."

Two-thirds (18 of 24) of the equations that need to be rederived pertain to the spring (17 equations) and fall (18 equations), which are recognized climatologically as transitional seasons.

4.2 Comparison of TRC Equations and Navy Equations

Section 3.2 described experiments for comparing the Navy regression equations in the 200–100-mb extrapolation interval with an equation derived through the TRC screening-regression program. Both equations were tested on the same independent data.

Of the five possible "predictors" designated at TRC ($200Z_0$, $200T_0$, $200-150H_{-12}$, $150-100H_{-12}$, and $100Z_{-12}$), all except $150-100H_{-12}$ significantly reduced the variance of the predictand ($100Z_0$). The predictors for the Navy equation are $200Z_0$ and $200T_0$. The results are presented in Table 4-1.

To test the significance of the improvement shown by the TRC equation in specifying the 100-mb height, "Student's" t-test for paired comparisons (described by Wadsworth and Bryan [15]) was performed on the 100 cases. The results of this test indicated that the difference between the TRC and Navy RMSEs is significant at less than the 1% level; i.e., the difference is highly significant. In the 100 cases, the TRC "prediction" was better than the Navy's 66 times, and tied with the Navy "prediction" eight times.

It should be kept in mind that, in our regression experiments, we specify shorter extrapolation intervals than does the Navy (e.g., 200–150 and 150–100 mb, rather than 200–100 mb, as in the above comparisons). This allows an analysis to be performed at the 150-mb level before extrapolating to 100 mb. Use of the shorter extrapolation intervals should logically result in lower RMSEs and, in fact, does result in lower RMSEs, as evidenced by the results for $100Z_0$ in the 25–35° latitude band for January.

4.3 Comparison of Objective and Subjective Wind Analyses at 100 mb

Table 4-2 presents the results of the comparison of the objective and subjective wind analyses. It is evident that the objective analyses could generally be considered at least as good as the subjective analyses. The analyses themselves are illustrated in Figs. 4-10 through 4-12. The observations at the station withheld from the analyses are indicated on these charts.

TABLE 4-1
COMPARISON OF INDEPENDENT-DATA ERRORS,
NAVY vs TRC VERTICAL-EXTRAPOLATION REGRESSION EQUATIONS
FOR 200-100-mb HEIGHT

Latitude band, °N	Number of cases	RMSE, ft		Largest error, ft	
		Navy	TRC	Navy	TRC
25-30	42	106.0	82.4	230	160
30-35	58	95.9	77.7	250	190
25-35	100	100.3	79.8	—	—

TABLE 4-2
OBJECTIVE vs SUBJECTIVE WIND-ANALYSIS ERRORS AT 100 mb

Map	Wind analysis RMSE based on withheld data, knots					
	u-component		v-component		Vector wind	
	Objective	Subjective	Objective	Subjective	Objective	Subjective
1	7.4	9.9	7.6	8.4	10.6	13.0
2	13.5	14.5	9.4	10.4	16.4	17.9
3	8.6	9.2	11.2	9.4	14.1	13.2

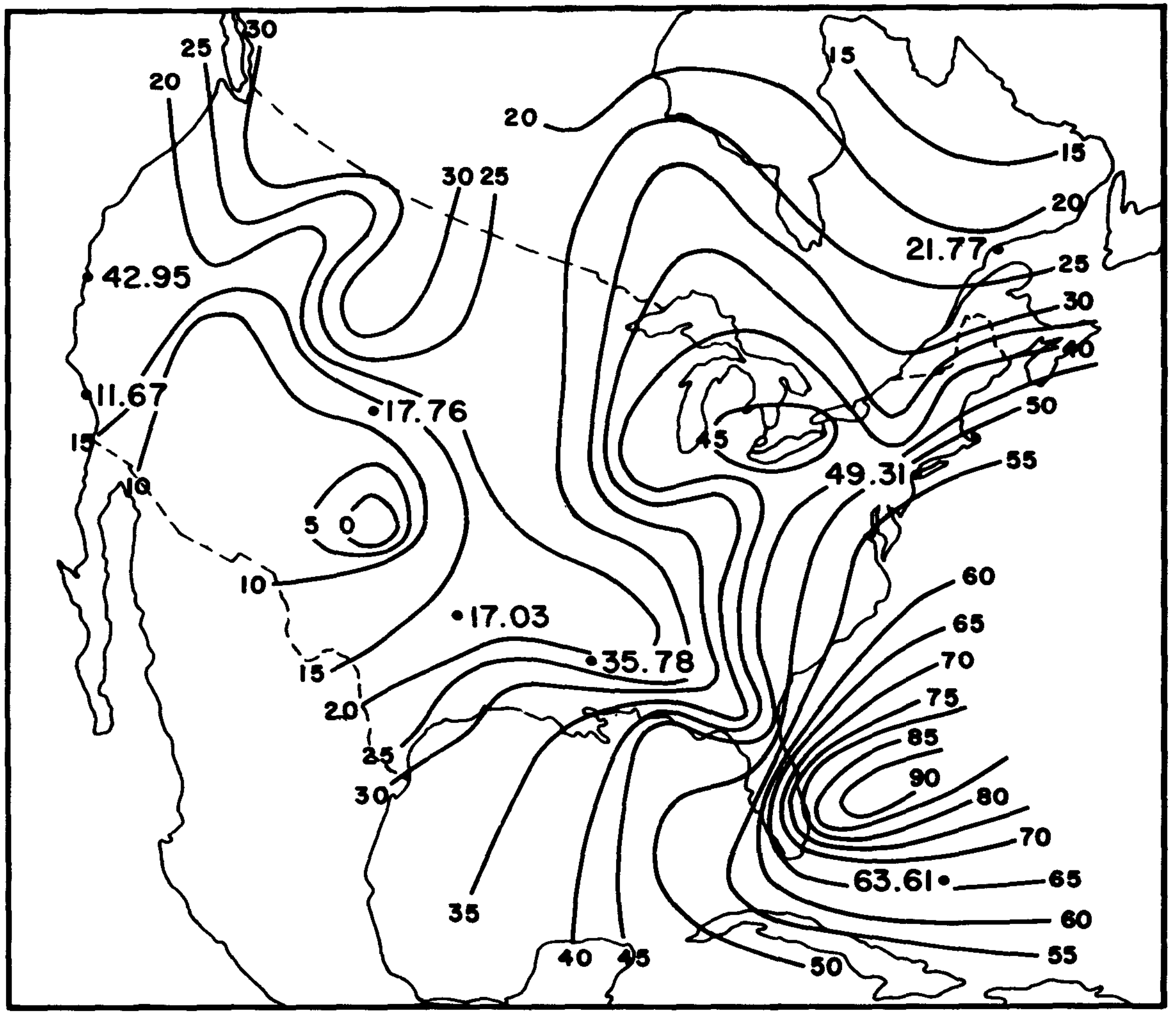


Fig. 4-10. Comparison of objective and subjective analyses of wind components for 1200Z, 12 Jan. 1959. (a) u_0-component, subjective analysis.

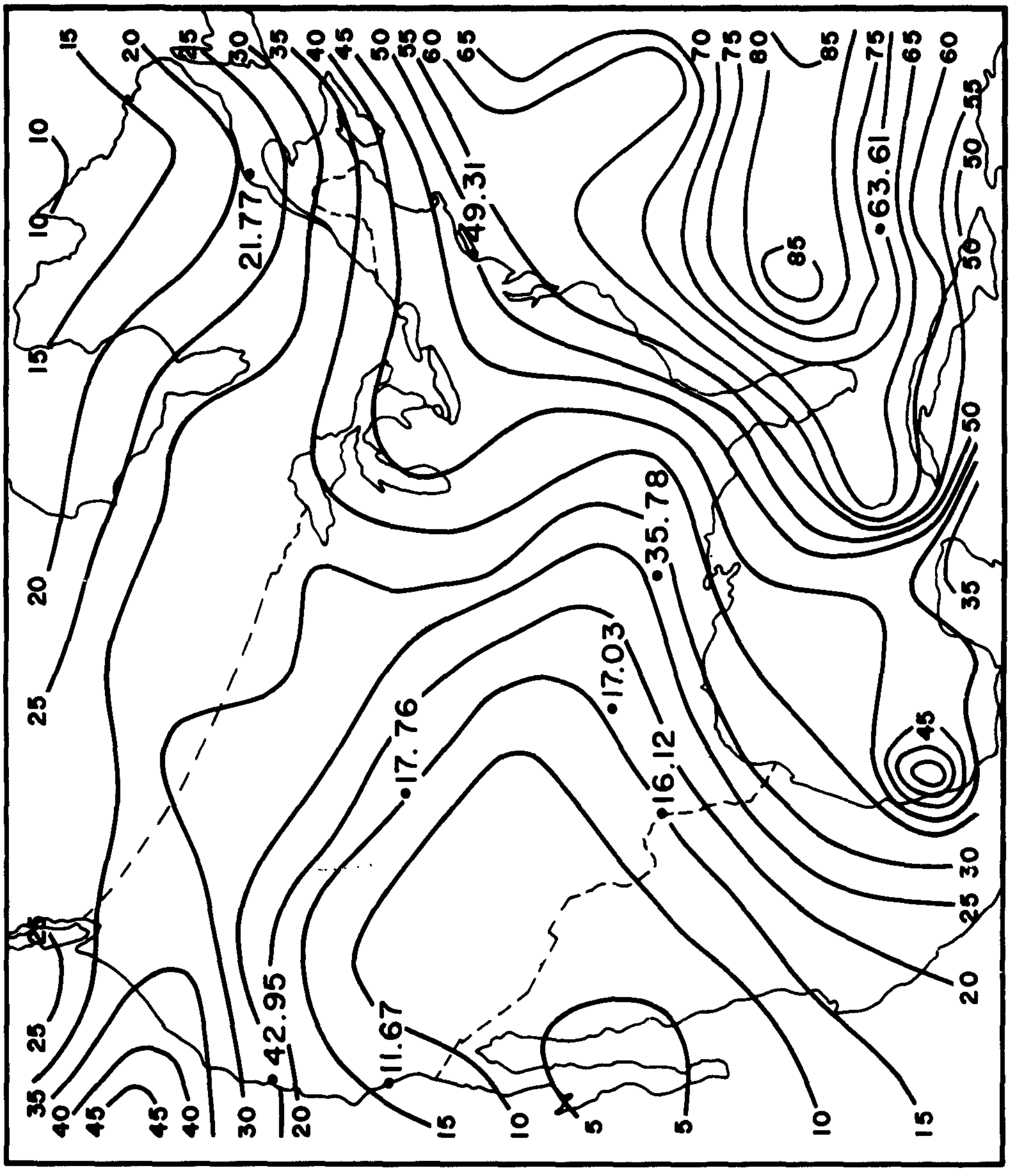


Fig. 4-10. (b) u_0-component, objective analysis.

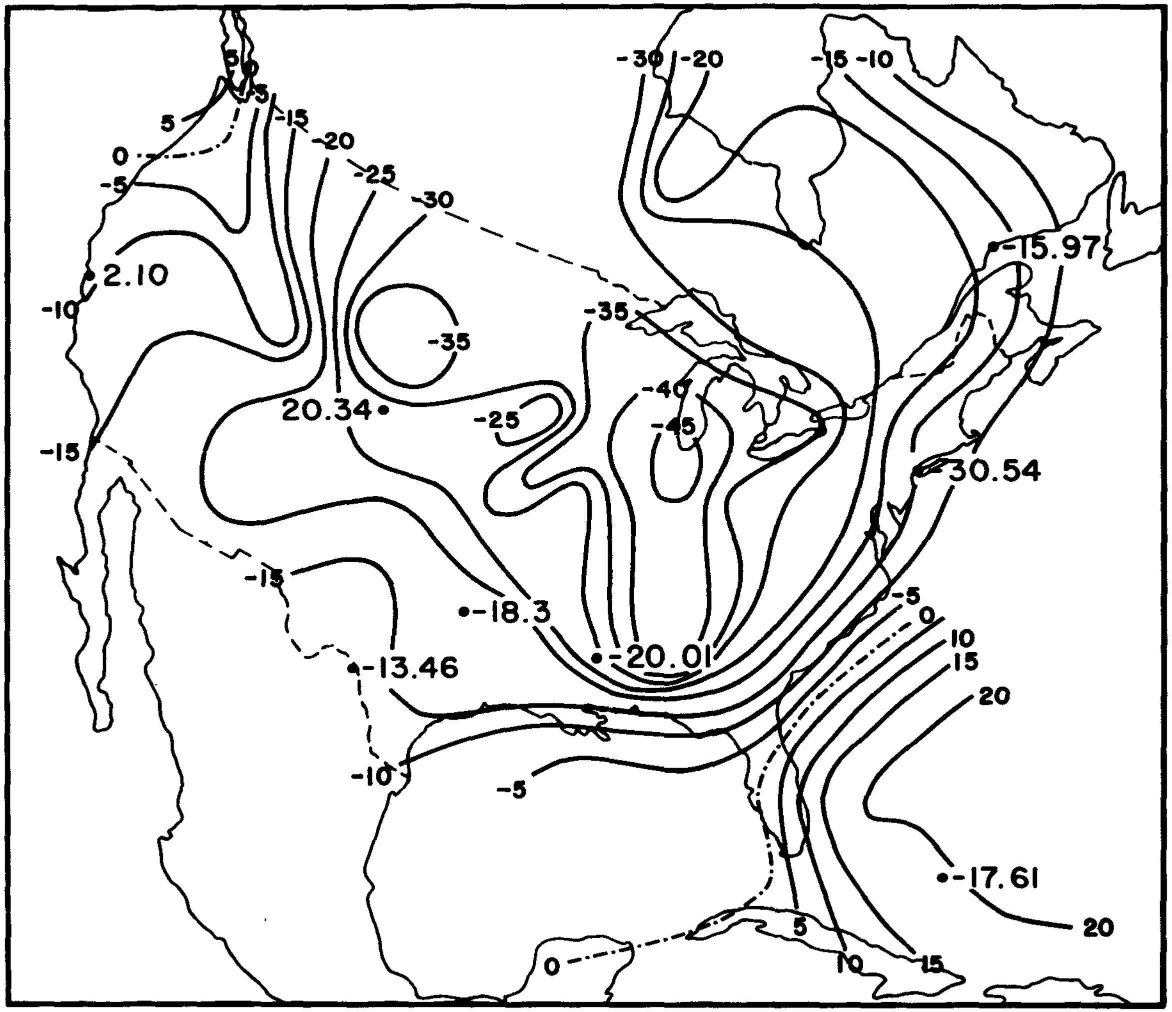


Fig. 4-10. (c) v_0-component, subjective analysis.

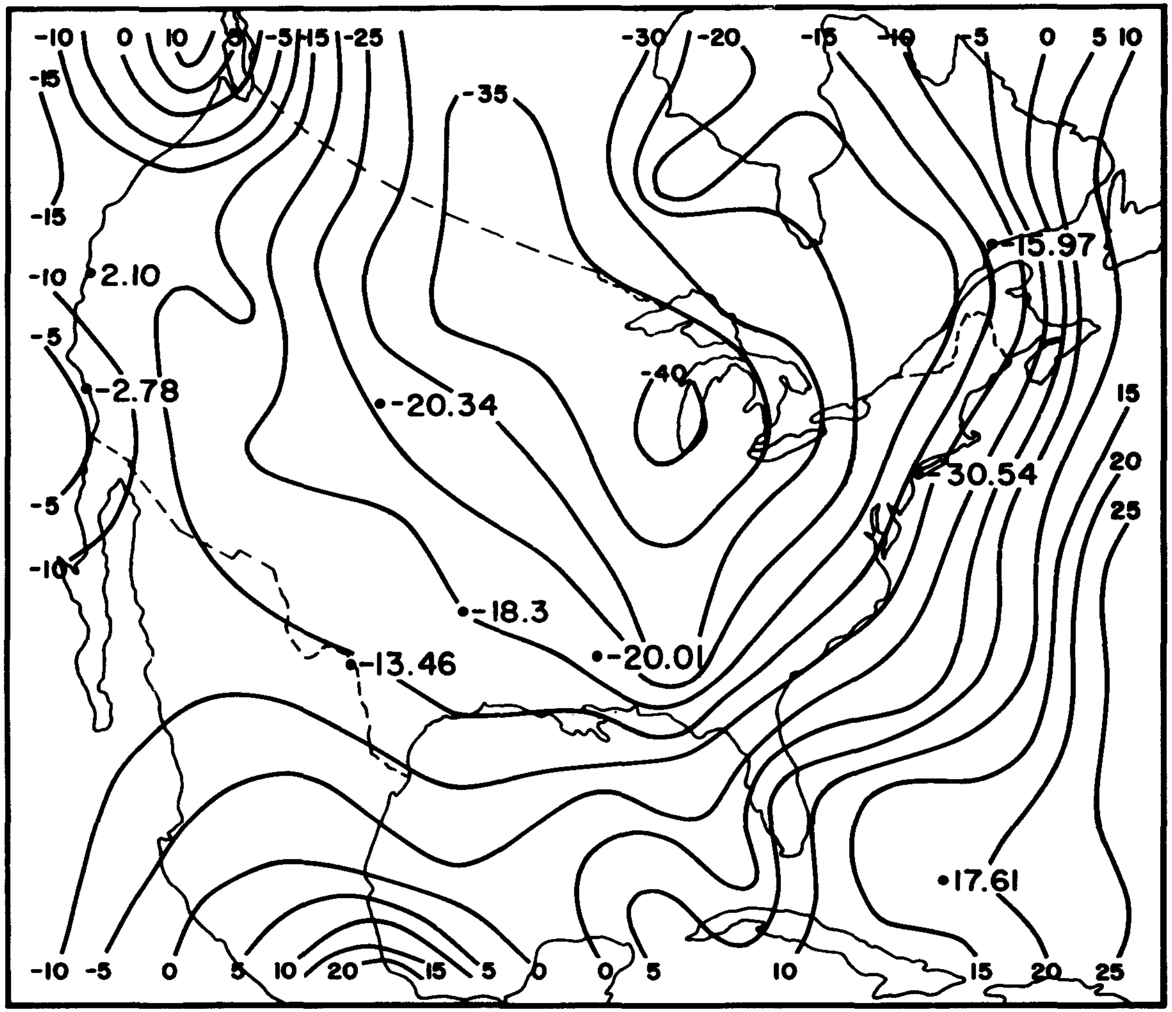


Fig. 4-10. (d) v_0-component, objective analysis.

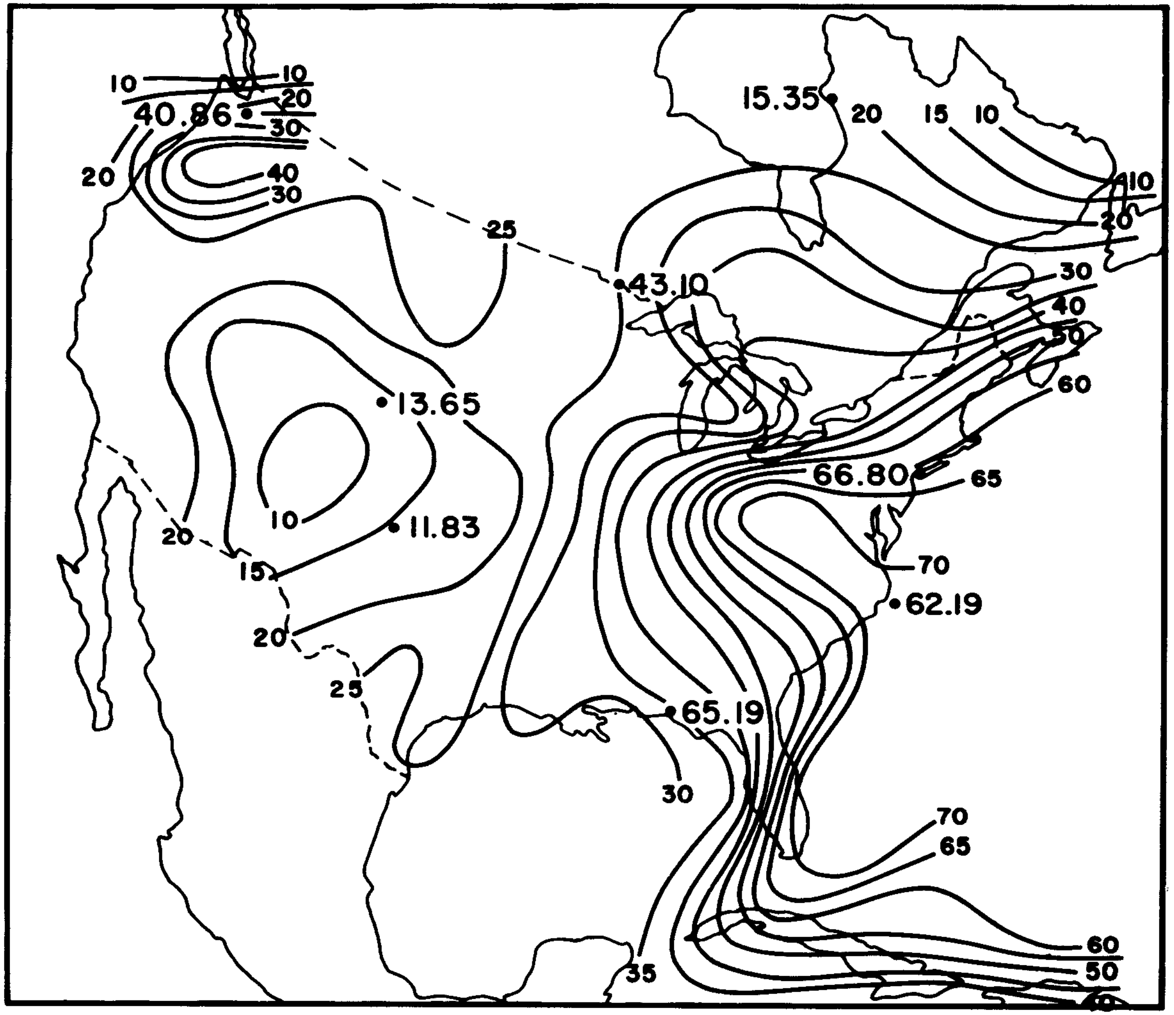


Fig. 4-11. Comparison of objective and subjective analyses of wind components for 0000Z, 13 Jan. 1959. (a) u_0-component, subjective analysis.

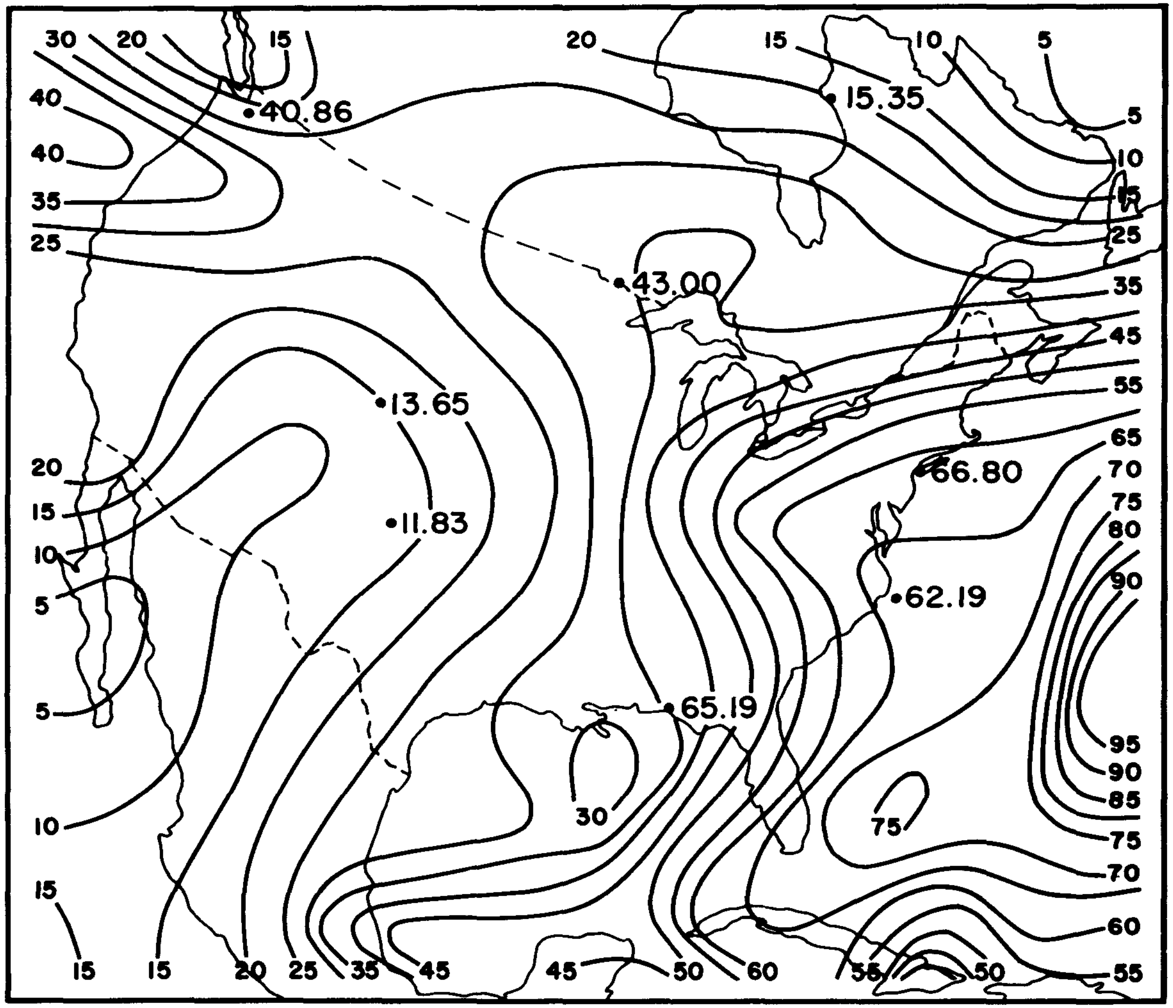


Fig. 4-11. (b) u_0-component, objective analysis.

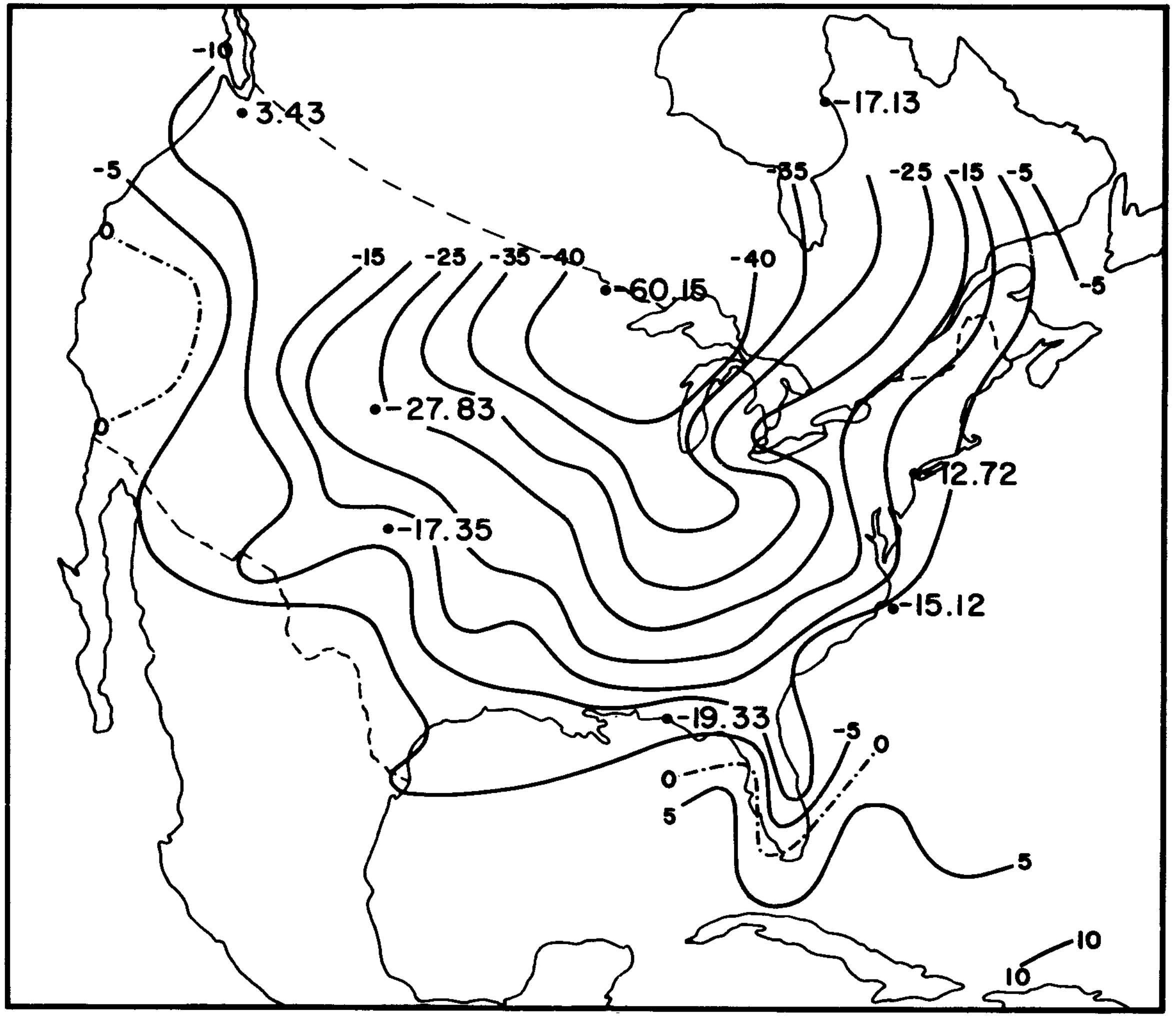


Fig. 4-11. (c) v_0-component, subjective analysis.

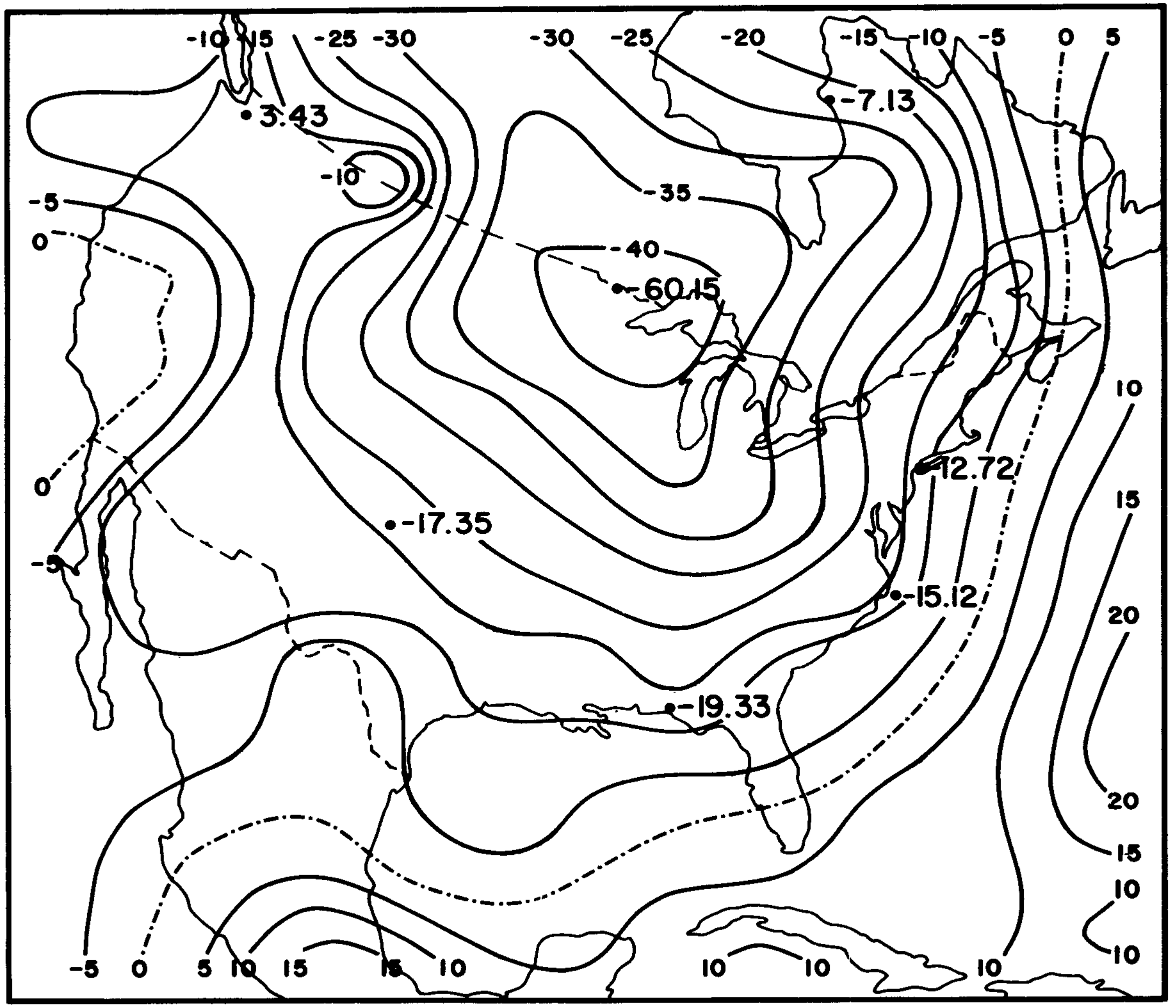


Fig. 4-11. (d) v_0-component, objective analysis.

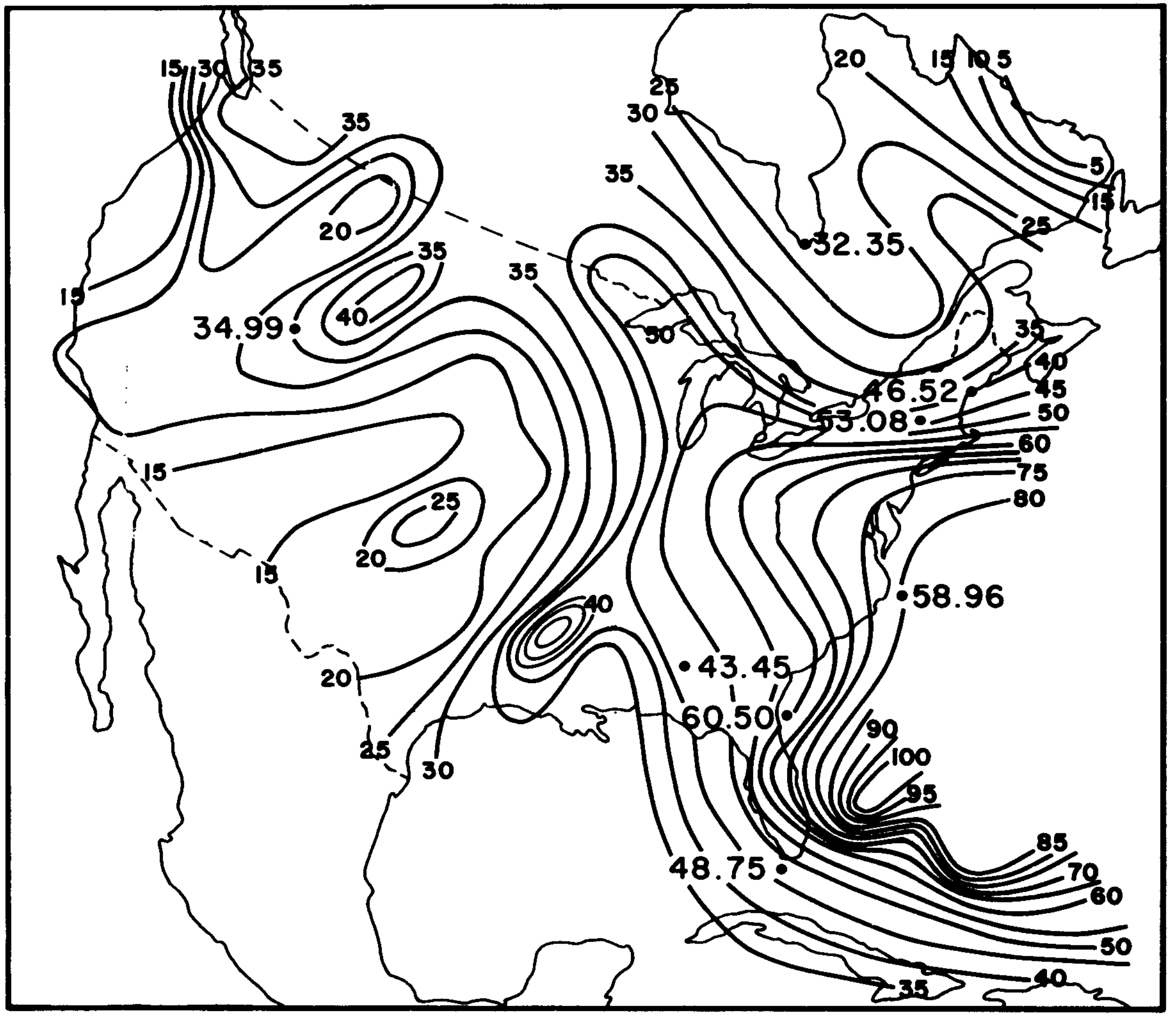


Fig. 4-12. Comparison of objective and subjective analyses of wind components for 1200Z, 13 Jan. 1959. (a) u_0-component, subjective analysis.

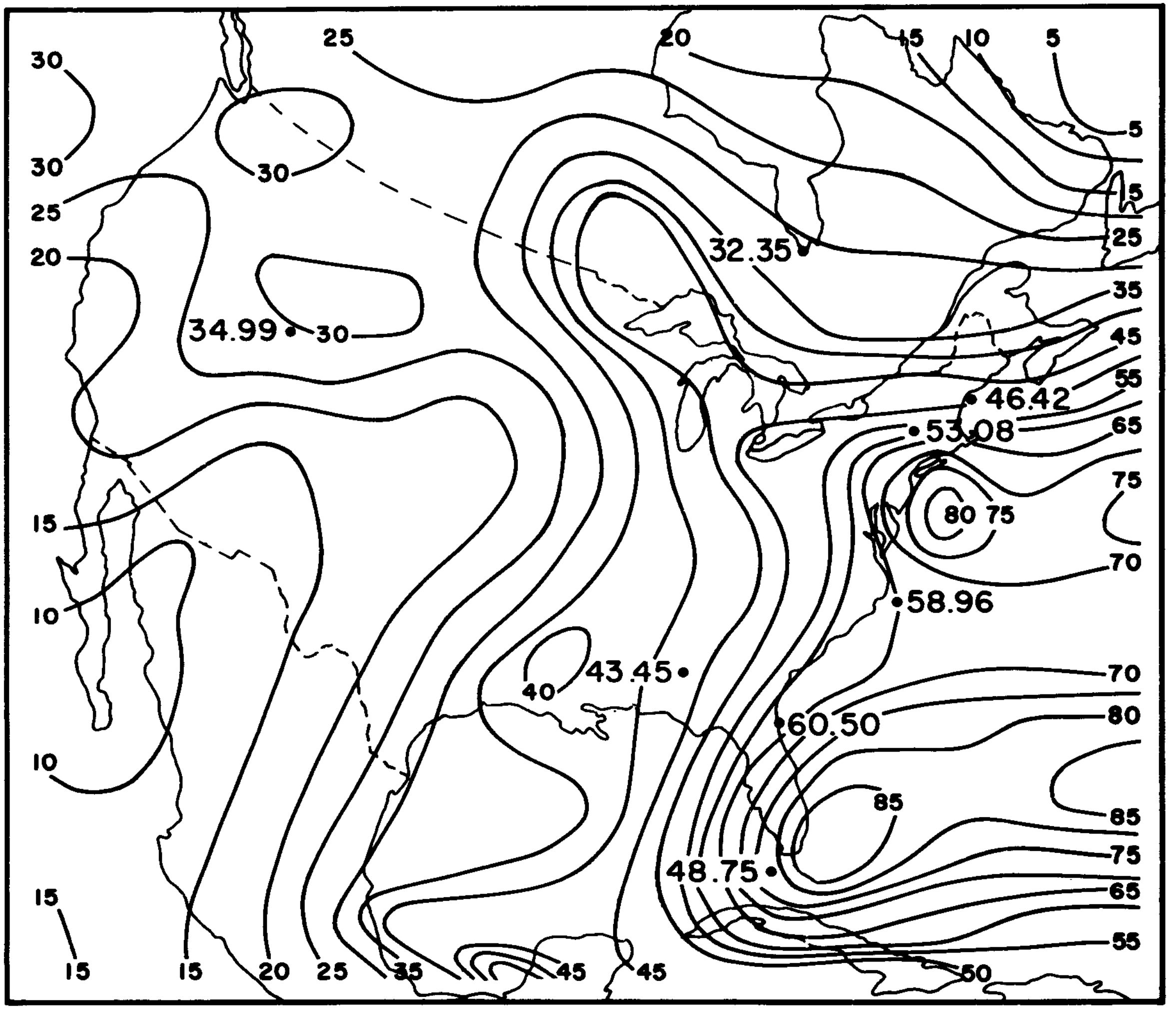


Fig. 4-12. (b) u_0-component, objective analysis.

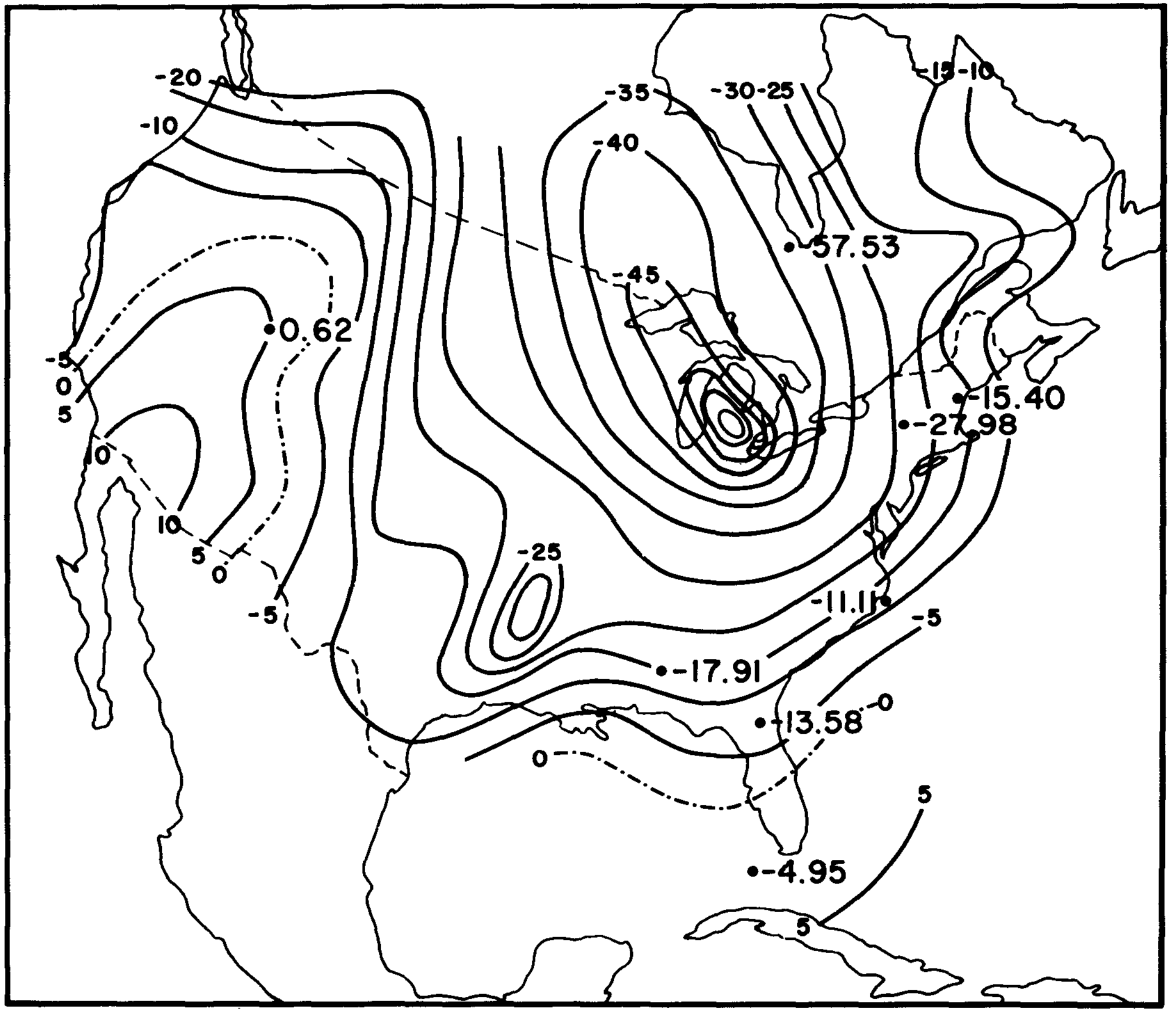


Fig. 4-12. (c) v_0-component, subjective analysis.

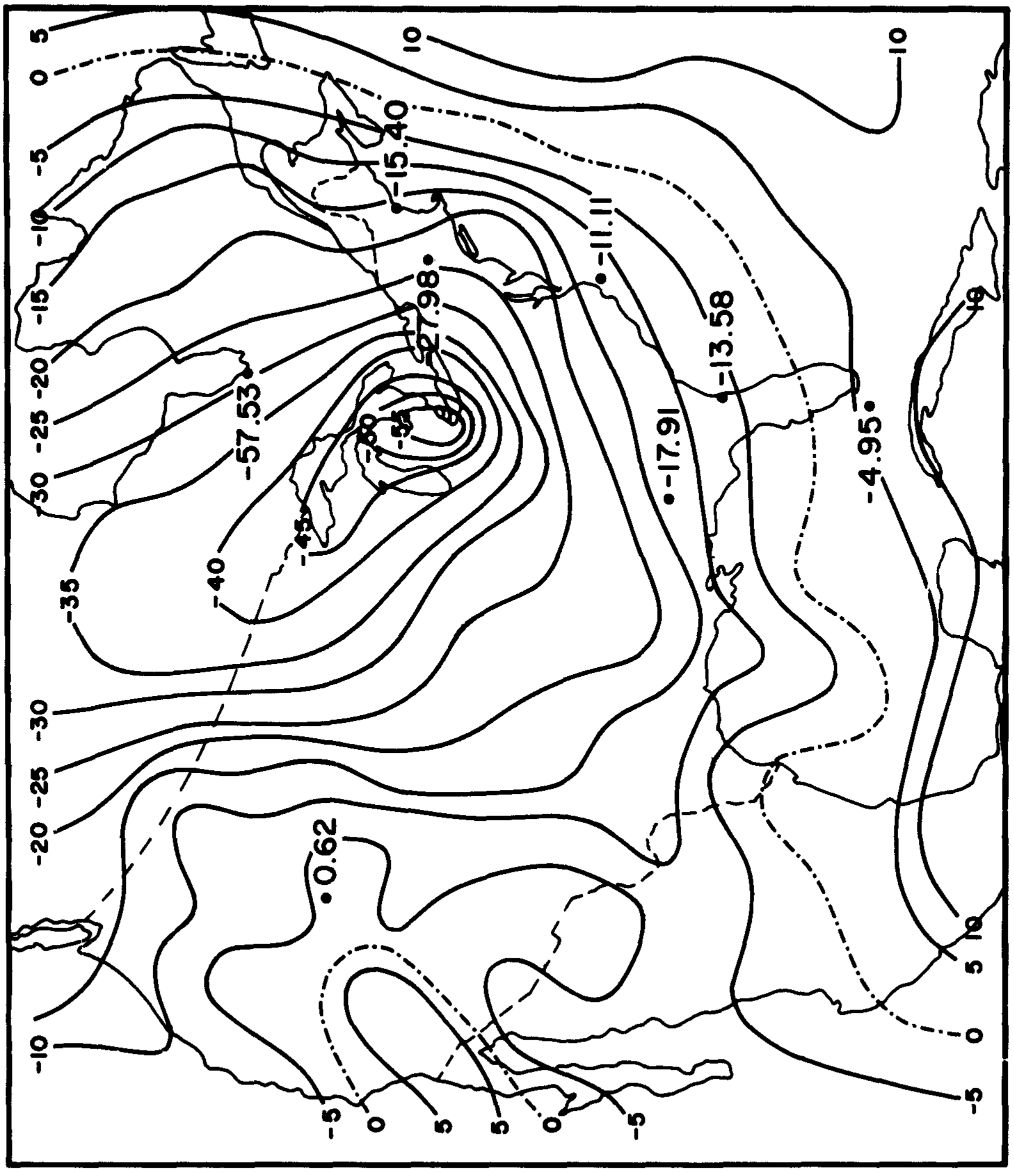


Fig. 4-12. (d) v_0-component, objective analysis.

4.4 Developmental Testing of the Objective Analyses, and Verification by the Areal-mean-error Method

With major concentration placed on derivation and testing of the vertical-extrapolation regression equations, the developmental testing of the analysis technique was necessarily limited. The testing nevertheless has enabled us to specify for the variable parameters in the analysis procedure a set of values that will produce good–if not necessarily optimum–analyses.

The three products at each constant-pressure surface treated by the build-up analysis procedure (see Sections 2.2 and 2.3) are height, temperature, and wind. In our developmental test program, the major emphasis has been placed on obtaining the best wind and temperature analyses, whereas the height analyses were considered primarily as a means for generating initial guesses to direct wind analyses; i.e., the assignment of different values to the variable parameters in the height analysis has been directed toward minimizing the errors in the gradient wind field as computed from the height analysis rather than toward minimizing the errors in the height field.

The following sections discuss the developmental testing and the verification statistics obtained from the areal-mean-error method. The height and wind analyses and statistics are considered separately from the temperature analysis and statistics.

4.4.1 Height and Wind Analyses and Verification

The variable parameters in a height analysis are the influence radius R, a weighting factor n, the "correction type," and smoothing.

R, the influence radius from a gridpoint, determines the stations to be used in applying a correction to the gridpoint and is of prime importance in the distance-weighting factor

$$W(d) = \frac{R^2 - d^2}{R^2 + d^2} \qquad (4\text{-}1)$$

in the correction equation. W(d) is, therefore, proportional to R. From developmental testing performed on a North American grid, it was found that the differences obtained in the verification statistics by varying the R's within reasonable limits are too small to be considered of any importance. Hence, it was decided to use the same R's used by the NWP Unit in their 500-mb analyses–since they produce verifications at least as good as any other set of R's tried. The radii are 5.9, 3.6, 2.2, and 1.5. Because the amount of available data diminishes as higher levels are analyzed, the NWP analyses above 500 mb use larger radii for the first two phases of their objective hemispheric analyses ($R_{1,2}$ = 6.9 and 3.9 at 300 mb; $R_{1,2}$ = 7.9 and 4.5 at 200 mb). Although it may be necessary to use larger radii in hemispheric analyses above 500 mb, it was not feasible to do so on the North American grid used in our developmental testing.

n is a weighting factor in the correction equation and weights the station observation relative both to the initial guess at the gridpoint and to the winds [see Eq. (2-1)]. As $n \rightarrow 0$, the winds are effectively weighted as 1.

Three possible types of correction may be applied to a gridpoint during a height analysis. Type 1 corrections use only the reported station height itself. Type 2 corrections use both the reported height and the reported wind. Type 3 corrections use only the wind.

The analysis procedure allows for a choice of correction on each pass. Although it would appear useful to include all available data for all scans, experience has shown that <u>not</u> using the winds during the first pass assists in obtaining a specification of the height field more quickly than if both heights and winds are used. To approach the correct value with one scan through the data, the weighting factor n is assigned a high value relative to the initial-guess value at all levels in the analysis build-up. After the first pass, all available data are used, and the type of correction applied is determined solely from the information reported by a station.

After the first pass of the analysis, a value for the weighting factor n must be determined which will result in a near-optimum analysis at each constant-pressure surface. (Since all available data are used for passes 2 through 4, n weights the reported heights relative to the winds as well as to the initial-guess value of height at the gridpoints.)

It has been concluded [2, 13] that the wind information is a better determinant of height gradient than the heights themselves. [The winds in the correction equation (2-1) for height analysis are geostrophic.] The NWP correction equation originally [2] weighted the winds in a 500-mb analysis 4:1 over the heights. This has since [9] been changed to 8:1. S. Teweles has recommended that, in objectively analyzing 100-mb heights, the weighting factor of winds over heights should be increased to 32:1 and suggests [13] that the factor should, perhaps, be 64:1 at 50 mb. He reasons that although radiation corrections are applied to the stratospheric data, instrumental errors increase as the radiosonde balloon rises. The winds, therefore, should be a more reliable indicator of the height gradient than the heights themselves.

Experiments were run to test the effect of varying n between relatively large limits at 100 mb. In one experiment of five successive observation times in January 1959, the weighting factor was set at the 32:1 value [n = 0.031, Eq. (2-1)] suggested by Teweles. In another experiment, with other parameters the same, the winds were weighted only four times more heavily than the heights (n = 0.25). The results are presented in Table 4-3, and an example of how the analyses themselves compared is given in Fig. 4-13.

In Fig. 4-13(b), in which the weighting factor of winds over heights is 4:1, the trough extending southward from central Canada through the west central United States is deeper than the trough in Fig. 4-13(a), in which the weighting factor is 32:1. The difference in height of the trough between the two maps is more than 200 ft in the northern part, more than 100 ft over the west central United States, and negligible over the extreme southwestern United States.

TABLE 4-3
WIND-ANALYSIS VERIFICATION STATISTICS*†

(a) Root-mean-square error, u-component

Map	RMSE		RMSE-A		RMSE-W	
	n = 0.25	n = 0.031	n = 0.25	n = 0.031	n = 0.25	n = 0.031
1	9.710	10.985	8.082	8.337	11.100	13.105
2	11.523	12.511	9.890	10.916	12.949	13.922
3	10.237	10.654	7.945	8.938	12.101	12.128
4	11.319	13.169	9.429	10.502	12.932	15.377
5	10.745	13.019	8.838	10.112	12.358	15.383
Over-all	10.743	12.113	6.270	6.949	8.724	9.922

(b) Root-mean-square error, v-component

Map	RMSE		RMSE-A		RMSE-W	
	n = 0.25	n = 0.031	n = 0.25	n = 0.031	n = 0.25	n = 0.031
1	8.486	8.481	5.608	5.872	10.609	10.457
2	9.374	9.700	5.991	6.347	11.824	12.159
3	13.937	14.707	6.692	7.537	18.536	19.382
4	9.337	9.495	8.270	9.031	10.291	9.935
5	9.361	11.031	8.604	9.293	10.058	12.528
Over-all	10.337	10.950	5.110	5.554	8.986	9.437

(c) Average-vector wind error

Map	AVWE		AVWE-A		AVWE-W	
	n = 0.25	n = 0.031	n = 0.25	n = 0.031	n = 0.25	n = 0.031
1	12.896	13.878	6.957	7.212	10.859	11.857
2	14.855	15.831	8.177	8.930	12.401	13.072
3	17.293	18.160	7.346	8.268	15.655	16.169
4	14.673	16.236	8.870	9.796	11.688	12.947
5	14.250	17.064	8.722	9.712	11.269	14.030
Over-all	14.909	16.329	8.088	8.896	12.524	13.693

(d) Average wind speed on final pass

Map	AWS
1	38.527
2	40.271
3	42.535
4	43.391
5	45.074

*Comparison of errors at 100 mb for winds weighted 4:1 over heights (n = 0.25) against errors for winds weighted 32:1 over heights (n = 0.031) in analysis procedure.
†All RMSEs, AVWEs, and AWSs are in knots.

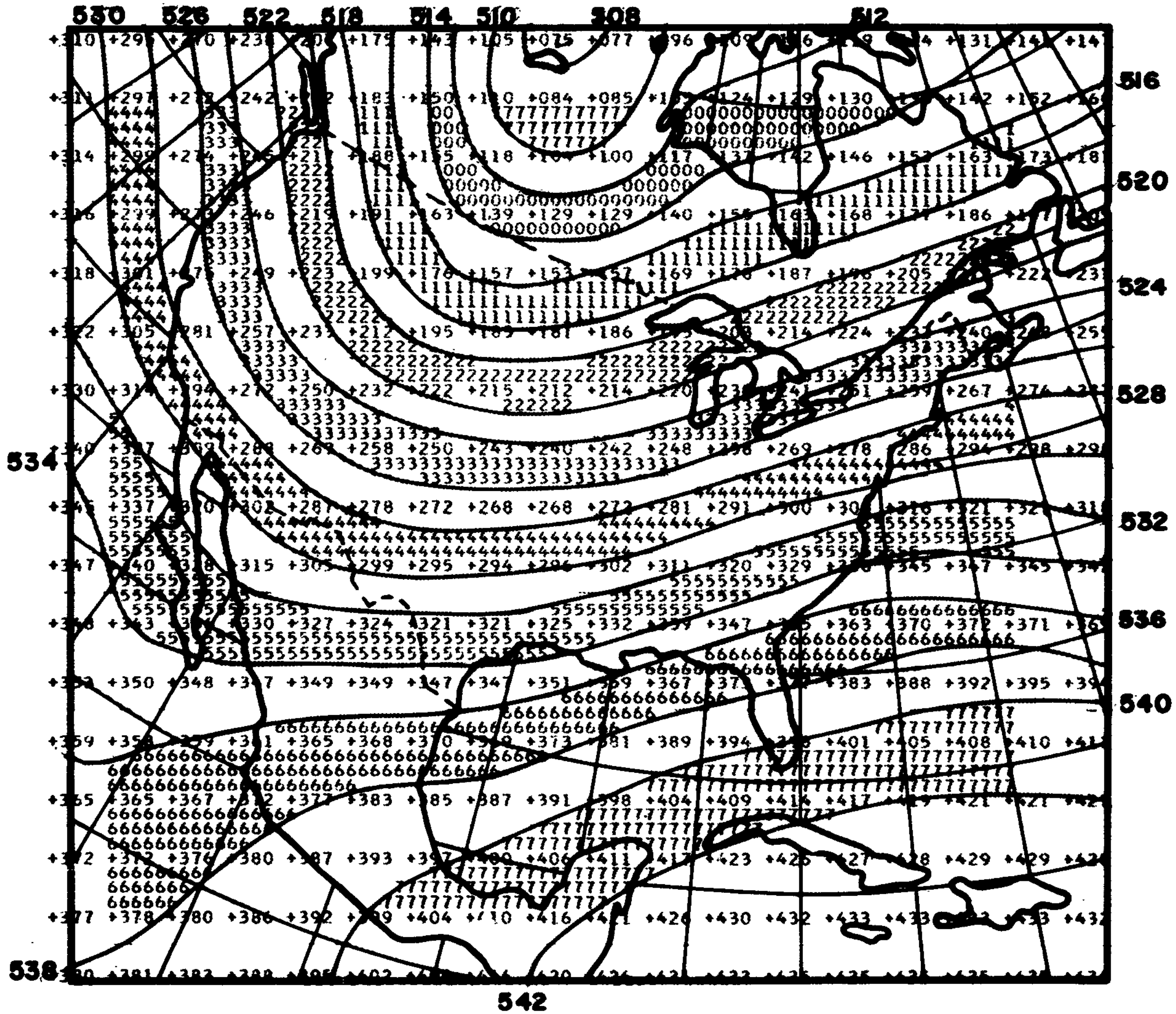


Fig. 4-13. Comparison of 100-mb analyses using different weights for winds in the analysis procedure. (a) Winds weighted 32:1 over heights.

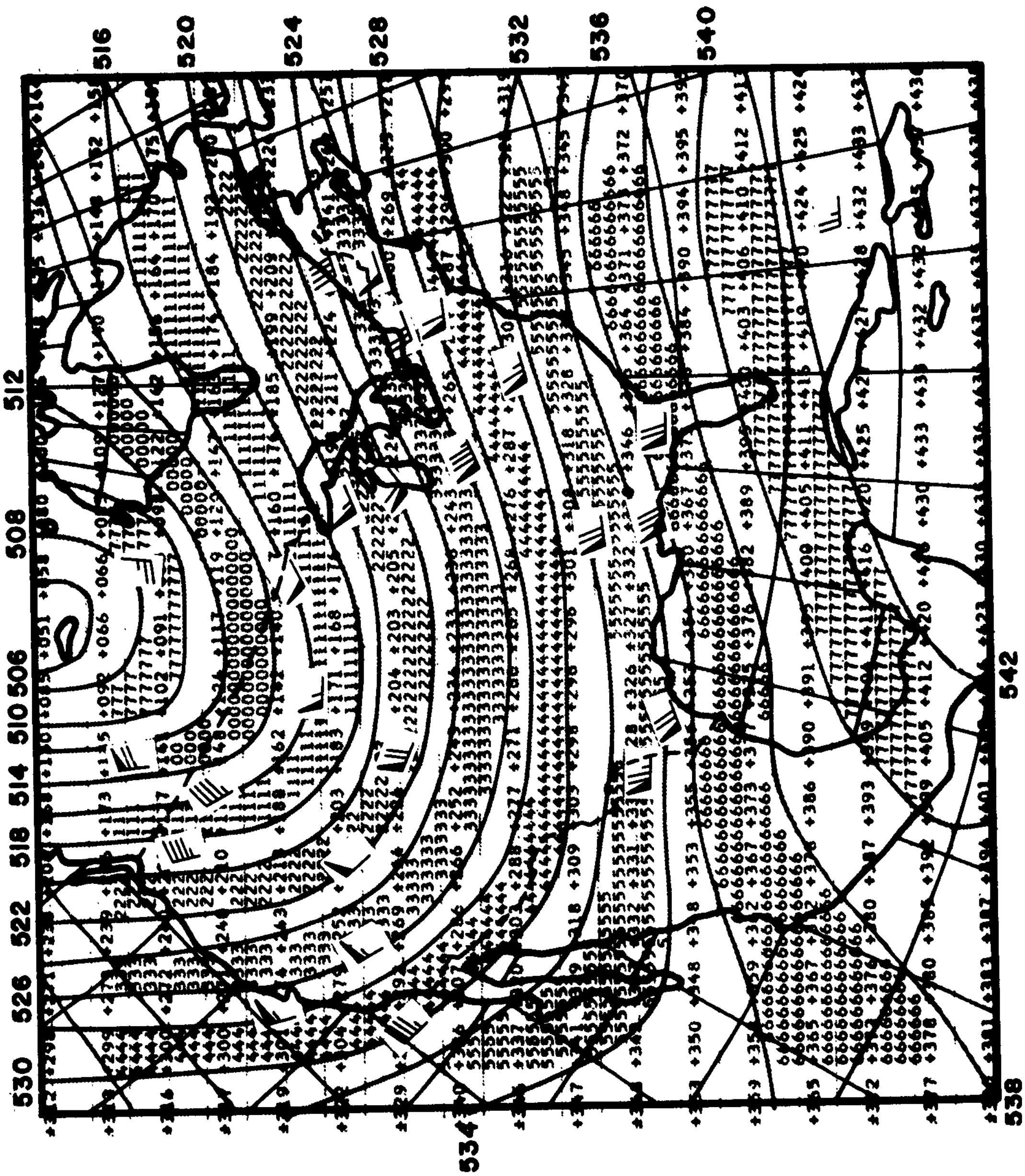


Fig. 4-13. (b) Winds weighted 4:1 over heights.

Note also that the ridge over eastern and northeastern Canada that appears in Fig. 4-13(b) does not appear in Fig. 4-13(a). This ridge is apparently an extension of the ridge off the East Coast. The minor ridge in Fig. 4-13(a) over the western edge of Hudson Bay is not evident in Fig. 4-13(b). The reality of this ridge may be questioned on the basis of its limited areal extent.

The results of the combined experiment, as evidenced by the verification statistics (Table 4-3) using the areal-mean-error method, are somewhat surprising, especially since the parameter being verified is the gradient wind as computed from the height analysis. In general, the 100-mb analysis, with the winds weighted 4:1 over the heights, results not only in better verification statistics but also in what is probably a more realistic analysis than the analysis with the winds weighted 32:1 over the heights.

The reported winds were plotted in Fig. 4-13(b) to ascertain whether cross-contour flow existed. Teweles [13] found it in 100-mb hemispheric analyses in which the winds were weighted at a ratio less than 32:1 over the heights. As can be seen, there is very little cross-contour flow on this particular North American analysis.

Apparently, analyses that weight the winds lightly give consistently better results than analyses that weight the winds heavily because the radiation-corrected 100-mb heights, though containing instrumental errors, are able to specify the contour-gradient field well enough to yield reasonably good computation of gradient winds. It is well known [9] that the winds are subgeostrophic in troughs and supergeostrophic in ridges; hence, the gradient winds are a better measure of the true winds in troughs and ridges than are the geostrophic winds.

The lighter weighting of the winds, though seemingly a more desirable feature in a 100-mb height analysis on a North American grid, may not be as desirable for analyses of hemispheric charts. The data are relatively dense on a North American grid, and the radiosonde instruments are more compatible over North America than over any other geographical area. Foreign radiosondes are not compatible, and, although corrections for radiation effects have been developed for them by Rothenberg and Teweles [8], changes in instrumentation (which have not, to date, been accounted for) lead to a lack of confidence in the height and temperature data reported by other countries. Therefore, the tendency is to weight the winds in a hemispheric 100-mb analysis more heavily than the 4:1 ratio suggested by the verification statistics for use on a North American grid.

Table 4-4 gives suggested values for n for use in hemispheric analyses at various constant-pressure surfaces.

Smoothing, the remaining variable parameter, eliminates the small-scale "wiggles" that generally appear in an analysis. Its evaluation here is particularly important because if each constant-pressure surface is smoothed after the final pass through the data, and the regression equations are used to extrapolate upward to obtain an initial guess at the next-higher level, the effect of smoothing becomes cumulative [7]. How much effect the accumulated smoothing has on the analyses at the levels in which we are most interested (100, 50, and 30 mb) remains to be determined. A decision as to what type of smoothing operator to employ, and when and where to use it, must be made on the basis of the verification statistics obtained during our developmental test runs.

The NWP Unit uses a complex 9-point operator designed by Schuman [10]. Their experience has been that a 5-point operator has undesirable characteristics. The 9-point operator effectively eliminates the subsynoptic-scale analysis "wiggles" of less than two NWP grid intervals. Further, it has some effect in reducing the amplitude of waves with wavelength between two and four grid intervals and leaves waves of wavelength greater than four grid intervals virtually unchanged.

Time was not available in our limited developmental testing either to design a smoothing operator such as the NWP Unit's complex operator or to adapt their smoothing program to our analysis program. Hence, it was necessary to design a simplified 9-point operator of the form

$$\langle Z \rangle = k_1 Z_0 + k_2 (Z_2 + Z_4 + Z_6 + Z_8) + k_3 (Z_1 + Z_3 + Z_5 + Z_7), \tag{4-2}$$

TABLE 4-4
WEIGHTING FACTOR n USED IN BUILD-UP ANALYSIS PROCEDURE

Level, mb	Pass 1, R = 5.9	Pass 2, R = 3.6	Pass 3, R = 2.2	Pass 4, R = 1.5
500	5.0	0.25	0.25	0.25
400	5.0	0.25	0.25	0.25
300	5.0	0.25	0.25	0.25
250	5.0	0.25	0.25	0.25
200	5.0	0.125	0.125	0.125
150	5.0	0.125	0.125	0.125
100	5.0	0.063	0.063	0.063
50	5.0	0.031	0.031	0.031
30	5.0	0.021	0.021	0.021

1	8	7
2	0	6
3	4	5

Fig. 4-14. The 9-point mesh used for smoothing.

where the subscripts refer to gridpoints in Fig. 4-14, and k_1, k_2, and k_3 are constants, the optimum values of which may be determined through testing of various combinations.

The main difference between TRC's 9-point operator and that used by the NWP Unit is that the TRC operator uses one set of real constants and one scan over the grid. This results in the central point's being influenced only by the eight surrounding points. The operator designed by Schuman, on the other hand, uses three elements (indices), two of which are conjugate complex indices, and three scans. This effectively smooths the field three times, and all of 48 surrounding points influence a smoothed point.

Four experiments using the build-up analysis procedure were run to test the effects of smoothing and the sensitivity of height analyses to different smoothing constants in Eq. (4-2). In all four experiments, the other variable parameters in the analysis procedure were kept constant; only the specifications for smoothing were varied. Temperature and wind analyses were not smoothed. Each of the experiments was run on data from the first five observation times of January 1959, and the analyses were performed on a North American grid. In all cases where smoothing was applied, it was applied to the last pass of the analysis.

Experiment 1. Height analyses at all constant-pressure surfaces were smoothed, with the smoothing constants k_1, k_2, and k_3 [Eq. (4-2)] set equal to

0.8, 0.035, and 0.015, respectively. [For smoothing along the boundary (but not at corner points), Eq. (4-2) was suitably modified to include the five surrounding points, and smoothing at corner points was accomplished using only three surrounding points.]

Experiment 2. Smoothing, using the same values of k_1, k_2, and k_3 specified for experiment 1, was carried out for height analyses at only the 300-, 200-, and 100-mb levels.

Experiment 3. No smoothing was performed.

Experiment 4. Height analyses at all constant-pressure surfaces were smoothed, with $k_1 = 0.6$, $k_2 = 0.075$, and $k_3 = 0.025$.

The resulting analyses and verification statistics indicated the following.

(a) Smoothing at all levels with $k_1 = 0.6$, $k_2 = 0.075$, and $k_3 = 0.025$ resulted in too heavy a smoothing, filling cyclones and troughs, and weakening anticyclones and ridges to an undesirable extent.

(b) No smoothing at all was not satisfactory, as evidenced by the verification statistics presented in Table 4-5 for experiments 1, 2, and 3. The initial guesses (IG) in Table 4-5 refer to the gradient winds computed from the last pass of the height analysis, and final pass (FP) refers to the last pass of the wind analysis that uses wind observations to correct the initial guesses. It is seen that the over-all average-vector wind errors are consistently larger (above 500 mb) for the no-smoothing experiment (3) than for either of the other two experiments. Further evidence supporting the conclusion that no smoothing is unsatisfactory is given by Figure 4-15, which compares wind speeds resulting from a height analysis that was smoothed after the final pass and wind speeds resulting from a height analysis that was not smoothed. The unsmoothed analysis appears to produce unrealistic gradients, resulting in wind speeds that, at isolated gridpoints, are excessive in comparison with those at nearby gridpoints.

TABLE 4-5
OVER-ALL WIND-VERIFICATION STATISTICS FOR 5 hr*†

(a) 500-mb level

Parameter	Over-all u-RMSE	u-analysis RMSE	u-withheld RMSE	Over-all v-RMSE	v-analysis RMSE	v-withheld RMSE	Over-all average-vector wind error	Average wind speed over maps after final pass
IG, Exp. 1‡	17.82	10.96	22.69	14.91	12.27	17.14	23.24	
IG, Exp. 2¶	17.86	10.77	22.85	14.99	11.91	17.52	23.32	
IG, Exp. 3§	17.86	10.77	22.85	14.99	11.91	17.52	23.32	
FP, Exp. 1	14.42	5.18	19.71	11.57	4.34	15.77	18.48	40.14
FP, Exp. 2	14.30	5.12	19.56	11.64	4.23	15.91	18.44	40.52
FP, Exp. 3	14.30	5.12	19.56	11.64	4.23	15.91	18.44	40.52

(b) 400-mb level

Parameter	Over-all u-RMSE	u-analysis RMSE	u-withheld RMSE	Over-all v-RMSE	v-analysis RMSE	v-withheld RMSE	Over-all average-vector wind error	Average wind speed over maps after final pass
IG, Exp. 1	21.57	12.03	28.03	22.55	13.05	29.10	31.20	
IG, Exp. 2	21.84	11.91	28.49	22.89	12.56	29.84	31.64	
IG, Exp. 3	21.84	11.91	28.49	22.89	12.56	29.84	31.64	
FP, Exp. 1	19.17	5.40	26.55	20.59	6.08	28.48	28.13	50.01
FP, Exp. 2	19.45	5.29	26.98	20.87	5.94	28.92	28.53	50.76
FP, Exp. 3	19.45	5.29	26.98	20.87	5.94	28.92	28.53	50.76

(c) 300-mb level

Parameter	Over-all u-RMSE	u-analysis RMSE	u-withheld RMSE	Over-all v-RMSE	v-analysis RMSE	v-withheld RMSE	Over-all average-vector wind error	Average wind speed over maps after final pass
IG, Exp. 1	23.90	13.79	30.87	21.41	13.70	26.99	32.09	
IG, Exp. 2	23.72	13.39	30.75	21.53	13.90	27.08	32.03	
IG, Exp. 3	25.77	16.40	32.55	21.37	14.44	26.54	33.48	
FP, Exp. 1	22.06	6.52	30.51	18.94	6.04	26.09	29.08	60.72
FP, Exp. 2	21.19	6.15	29.33	19.00	6.02	26.17	28.46	61.27
FP, Exp. 3	22.58	6.53	31.25	18.41	5.91	25.35	29.13	62.82

*Beginning at 1200Z, 1 Jan 1959; ending at 1200Z, 3 Jan 1959.
†All entries are in knots.
‡Experiment 1: Smoothing at all levels (see text for values of k, smoothing constants).
¶Experiment 2: Smoothing at 300, 200, and 100 mb only.
§Experiment 3: No smoothing.

(d) 250-mb level

Parameter	Over-all u-RMSE	u-analysis RMSE	u-withheld RMSE	Over-all v-RMSE	v-analysis RMSE	v-withheld RMSE	Over-all average-vector wind error	Average wind speed over maps after final pass
IG, Exp. 1	23.99	14.88	30.49	18.28	11.02	23.39	30.17	
IG, Exp. 2	24.99	15.54	31.73	17.93	10.99	22.84	30.75	
IG, Exp. 3	25.51	16.13	32.27	17.94	11.16	22.78	31.19	
FP, Exp. 1	20.96	5.83	29.06	15.94	3.70	22.23	26.34	64.00
FP, Exp. 2	21.46	5.98	29.75	15.46	3.65	21.55	26.45	64.71
FP, Exp. 3	22.41	5.90	31.14	15.29	3.61	21.31	27.13	65.30

(e) 200-mb level

IG, Exp. 1	21.52	15.24	26.34	19.13	16.59	21.37	28.80	
IG, Exp. 2	21.83	15.21	26.87	18.93	16.15	21.35	28.90	
IG, Exp. 3	23.61	16.33	29.11	19.46	16.54	21.97	30.59	
FP, Exp. 1	15.51	4.26	21.51	13.91	3.05	19.43	20.83	62.82
FP, Exp. 2	15.36	4.48	21.25	13.14	3.00	18.33	20.21	63.76
FP, Exp. 3	17.14	5.22	23.67	13.58	3.18	18.93	21.86	64.92

(f) 150-mb level

IG, Exp. 1	15.92	14.20	17.48	12.63	11.17	13.93	20.32	
IG, Exp. 2	17.26	14.22	19.82	12.69	11.21	14.01	21.42	
IG, Exp. 3	17.84	14.85	20.39	13.40	11.28	15.23	22.31	
FP, Exp. 1	10.63	3.42	14.63	8.71	2.45	12.06	13.74	58.63
FP, Exp. 2	12.45	3.42	17.26	8.75	2.39	12.15	15.22	59.58
FP. Exp. 3	12.84	3.78	17.76	9.70	2.40	13.50	16.09	60.71

(g) 100-mb level

Parameter	Over-all u-RMSE	u-analysis RMSE	u-wihheld RMSE	Over-all v-RMSE	v-analysis RMSE	v-wihheld RMSE	Over-all average-vector wind error	Average wind speed over maps after final pass
IG, Exp. 1	10.21	8.00	12.02	8.62	5.97	10.63	13.37	
IG, Exp. 2	10.76	8.22	12.80	8.33	6.18	10.03	13.60	
IG. Exp. 3	13.24	9.50	16.13	9.48	6.93	11.47	16.29	
FP, Exp. 1	8.00	2.87	10.94	7.02	1.67	9.77	10.64	45.51
FP, Exp. 2	8.78	2.90	12.08	6.53	1.70	9.08	10.94	46.07
FP, Exp. 3	11.28	3.18	15.64	7.27	1.77	10.12	13.42	47.16

(h) 50-mb level

IG, Exp. 1	9.57	7.97	10.93	8.45	6.89	9.77	12.77	
IG, Exp. 2	9.69	7.86	11.21	8.21	6.70	9.49	12.70	
IG, Exp. 3	10.34	8.26	12.08	8.34	7.00	9.49	13.29	
FP, Exp. 1	7.49	2.16	10.38	5.87	1.64	8.13	9.52	27.84
FP, Exp. 2	7.74	2.15	10.73	5.59	1.61	7.75	9.55	28.39
FP, Exp. 3	8.25	2.09	11.48	5.43	1.63	7.51	9.88	29.92

(i) 30-mb level

IG, Exp. 1	11.46	9.53	13.11	9.01	6.33	11.04	14.58	
IG, Exp. 2	12.64	9.87	14.90	9.08	6.36	11.14	15.56	
IG, Exp. 3	13.77	9.90	16.77	8.89	6.52	10.70	16.38	
FP, Exp. 1	8.78	2.42	12.17	6.53	1.54	9.11	10.94	31.42
FP, Exp. 2	9.95	2.57	13.84	6.63	1.54	9.25	11.96	32.49
FP, Exp. 3	11.27	2.57	15.72	6.15	1.57	8.55	12.84	33.48

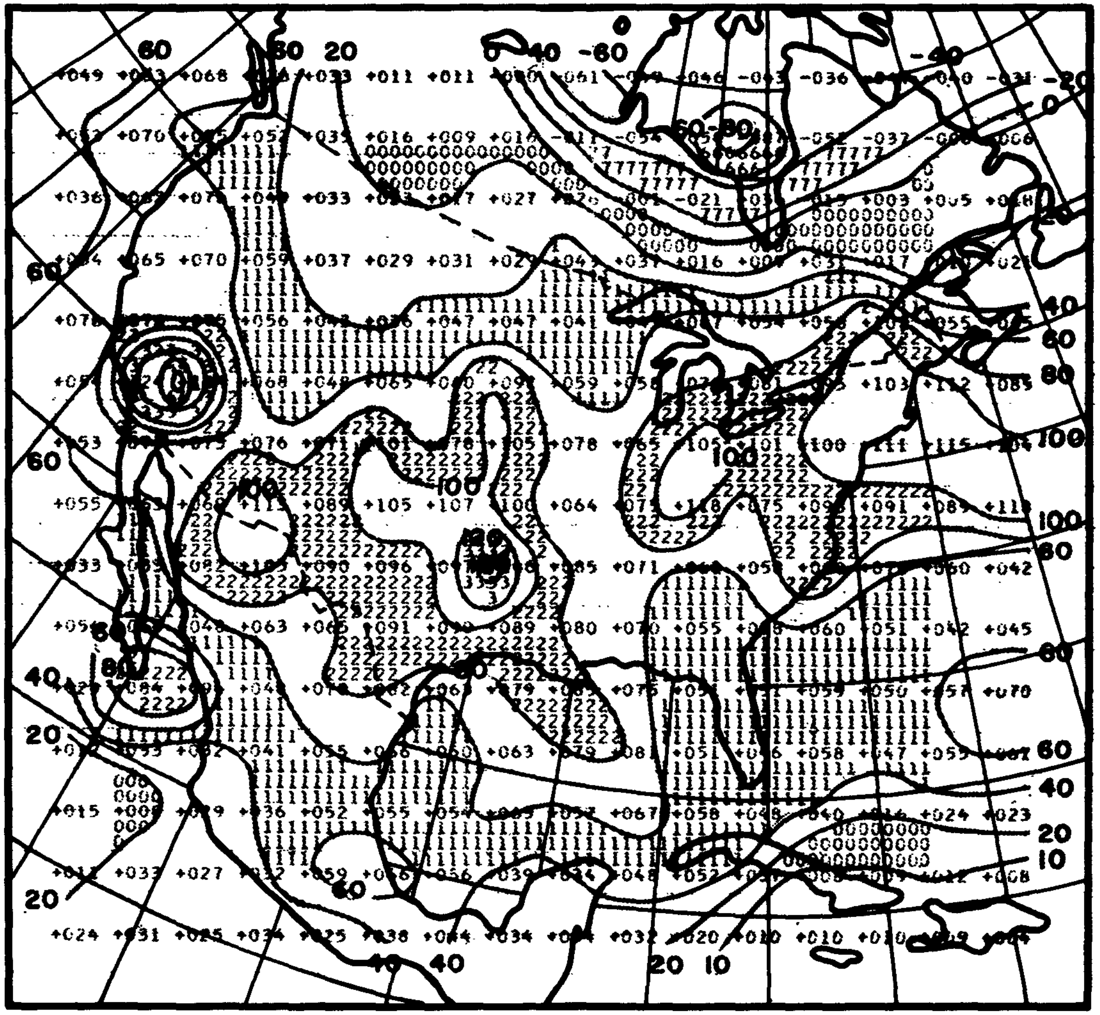


Fig. 4-15. Comparison of u-component gradient wind speeds at 300 mb. (a) Computed from unsmoothed height analysis.

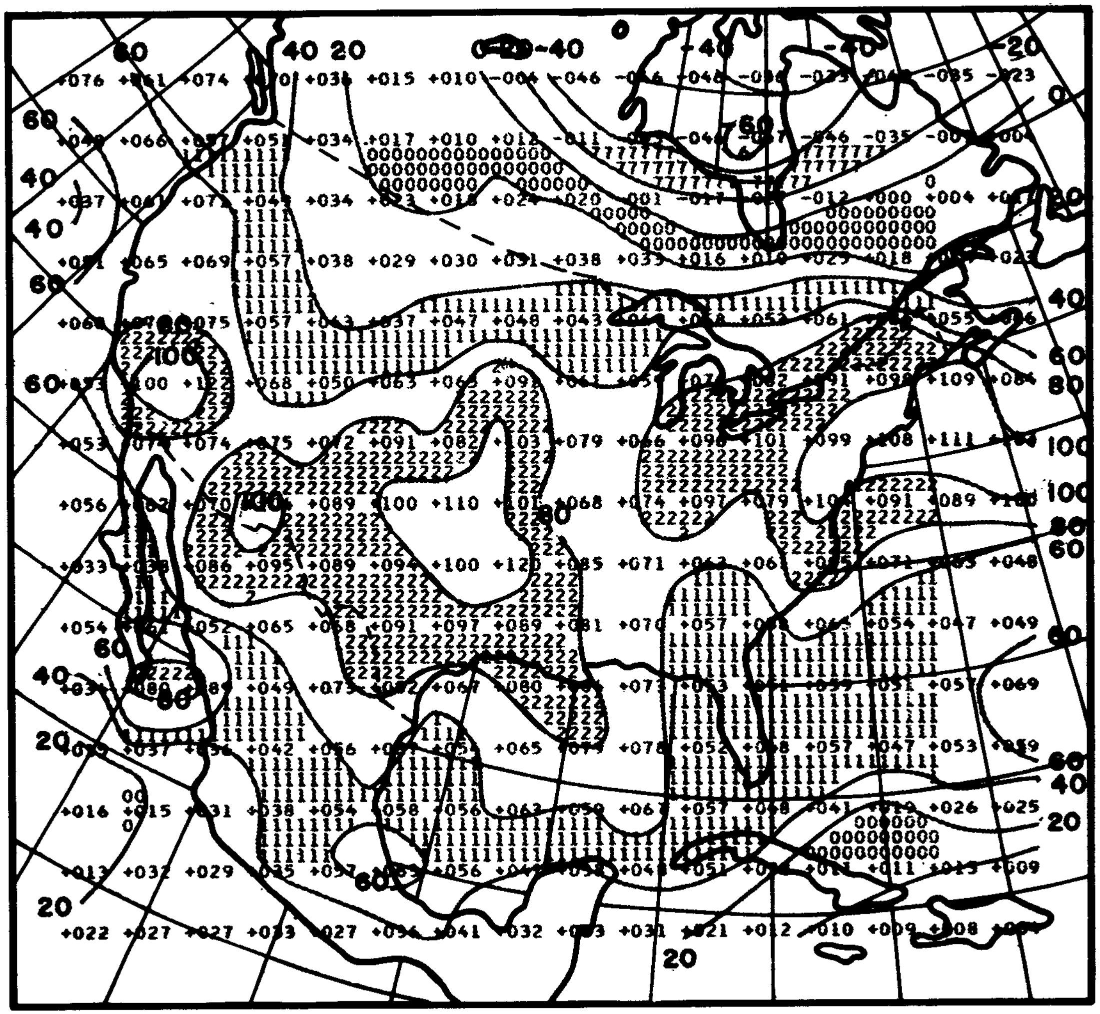


Fig. 4-15. (b) Computed from smoothed height analysis.

(c) The verification statistics listed in Table 4-5 show that there are negligible differences in the average-vector wind error at 100, 50, and 30 mb for experiments 1 (smoothing at all levels) and 2 (smoothing at 300, 200, and 100 mb). These statistics fail to answer the question of whether smoothing at all levels in a build-up analysis is preferable to smoothing at selected levels. The analyses themselves do not really answer this question either, for they appear to be quite similar over most regions of the analysis area. There is a tendency, however, for a 100-mb height analysis that has resulted from smoothing at selected levels to define troughs and ridges more clearly than an analysis that is smoothed at all levels. This tendency is demonstrated in Fig. 4-16. It is, therefore, left to the eventual user to determine which of the two alternatives he prefers for his analysis procedure. There does not seem to be much question that smoothing is necessary at the 100-mb level and is also desirable at least at other levels below 100 mb. Above 100 mb, a light smoothing should be used at 30 mb, since the verification statistics in Table 4-5 indicate that smoothing results in somewhat smaller errors.

In computing gradient winds from height analyses, a problem became evident after the initial computer run. The gradient winds computed below latitude 30°N resulted in excessively high west-wind components that turned out to be unrealistic in view of the contour spacing. The gradient-wind equation is

$$V_{gr} = \frac{fr}{2}\left[\left(\frac{4V_g}{fr} + 1\right)^{1/2} - 1\right], \tag{4-3}$$

where f is the Coriolis parameter, r is the radius of curvature of the contours in feet per grid unit, and V_g is the geostrophic wind in feet per second. (The Coriolis parameter, f, is equal to $2\omega \sin \phi = 14.584 \times 10^{-5} \sin \phi$ rad sec^{-1}, where ϕ is in degrees of latitude.) Apparently, the excessively high west-wind components occur when the square-root term in Eq. (4-3) has a negative value, in which case the wind is computed from -fr/2.

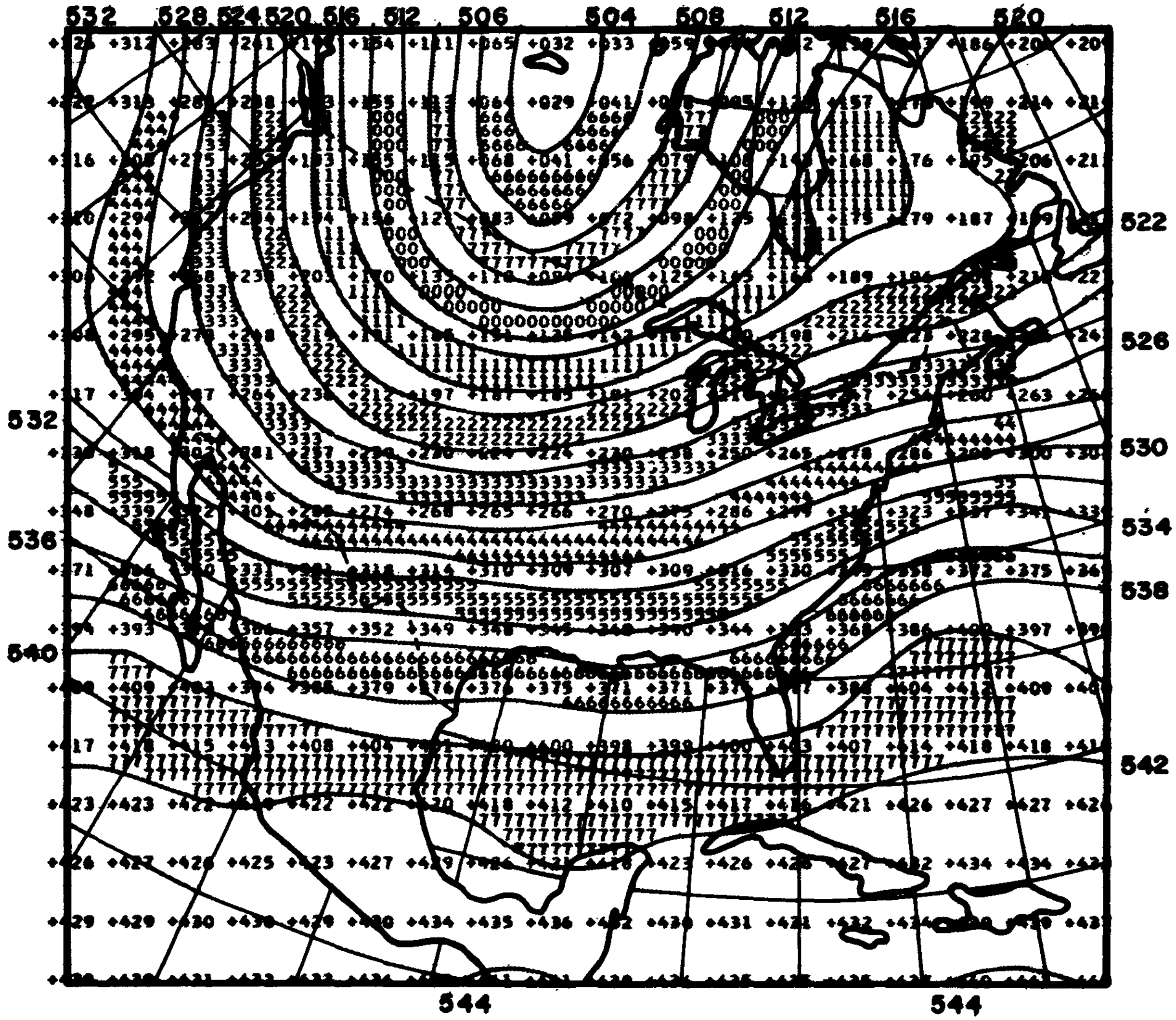


Fig. 4-16. 100-mb height analyses from build-up analysis procedure. (a) Smoothing was performed at 300, 200, and 100 mb in the analysis build-up.

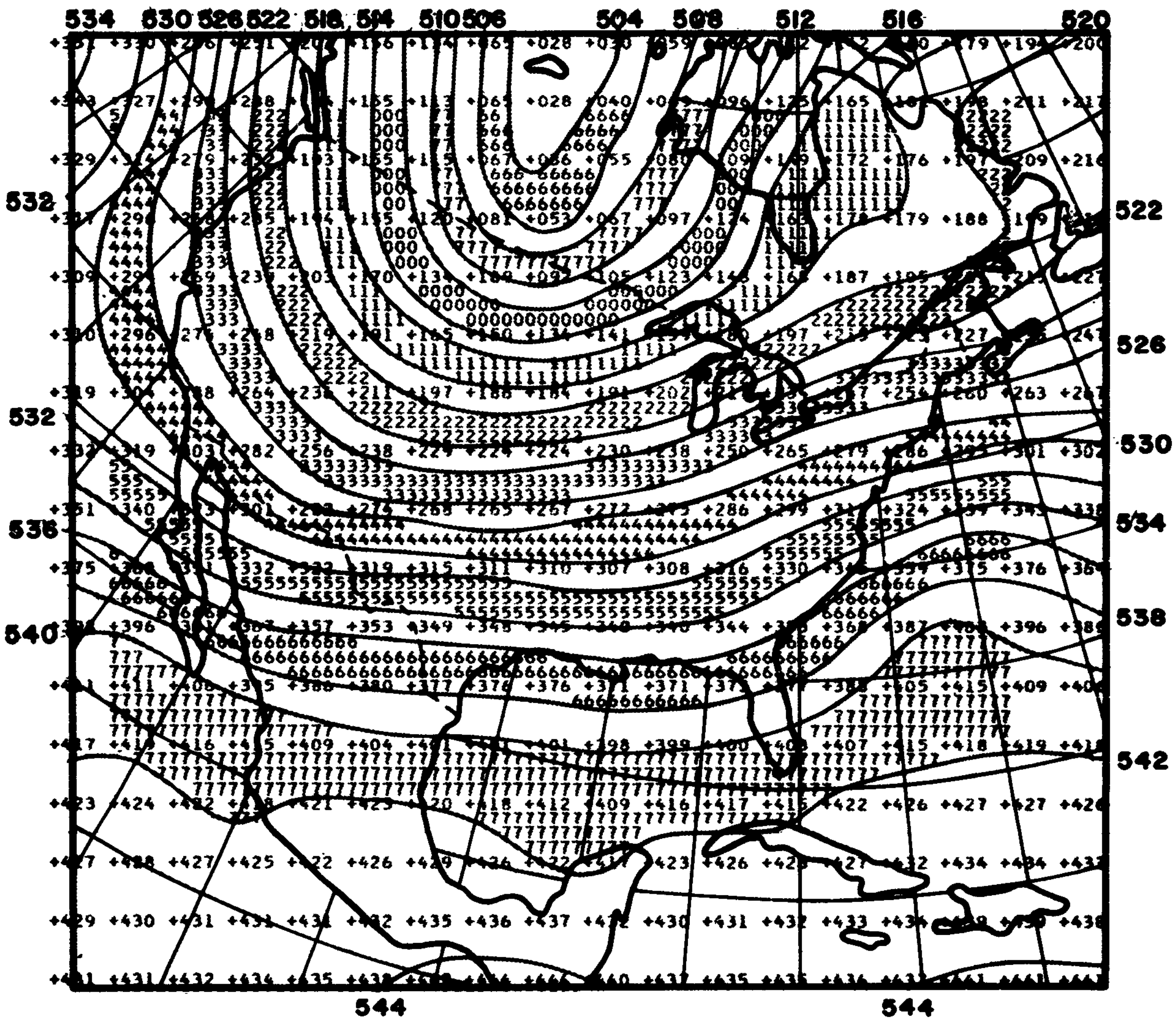


Fig. 4-16. (b) No smoothing was performed at any level in the analysis build-up.

A change in the program to compute geostrophic winds when the square-root term in Eq. (4-3) is negative helped somewhat, but fictitiously high west-wind components continued to appear in low latitudes. An investigation traced their cause to the occurrence of a slightly positive square-root term in Eq. (4-3), resulting in computation of gradient winds primarily from the -fr/2 term. To solve this problem, geostrophic winds were computed at those gridpoints where the curvature was anticyclonic (r negative) south of latitude 30°N. Results then indicated no fictitiously high west-wind components, nor were there any discontinuities in the wind field across the 30th parallel. The procedure of computing geostrophic winds as initial guesses when the contour curvature is anticyclonic south of 30°N was incorporated into the wind-analysis program and, as a result, no further problems were encountered in the developmental testing of the wind analysis.

The only variable parameter in our direct wind analysis is R, the influence radius. Initially, four passes through the data were tried, but verification statistics indicated that little, if any, improvement was gained from the fourth pass. Only limited developmental testing of the direct wind analysis was performed. Varying the R's for the u- and v-components (within reasonable limits) did not result in any marked difference in the verification statistics, hence the choice of a series of R's is rather arbitrary. However, in choosing the R's, it should be realized that the u-component of the wind generally has a longer wavelength than the

TABLE 4-6
R, INFLUENCE RADII, USED IN DIRECT WIND ANALYSES

Component	Influence radius R, grid units		
	Pass 1	Pass 2	Pass 3
u	2.8	2.1	1.4
v	2.5	1.8	1.25

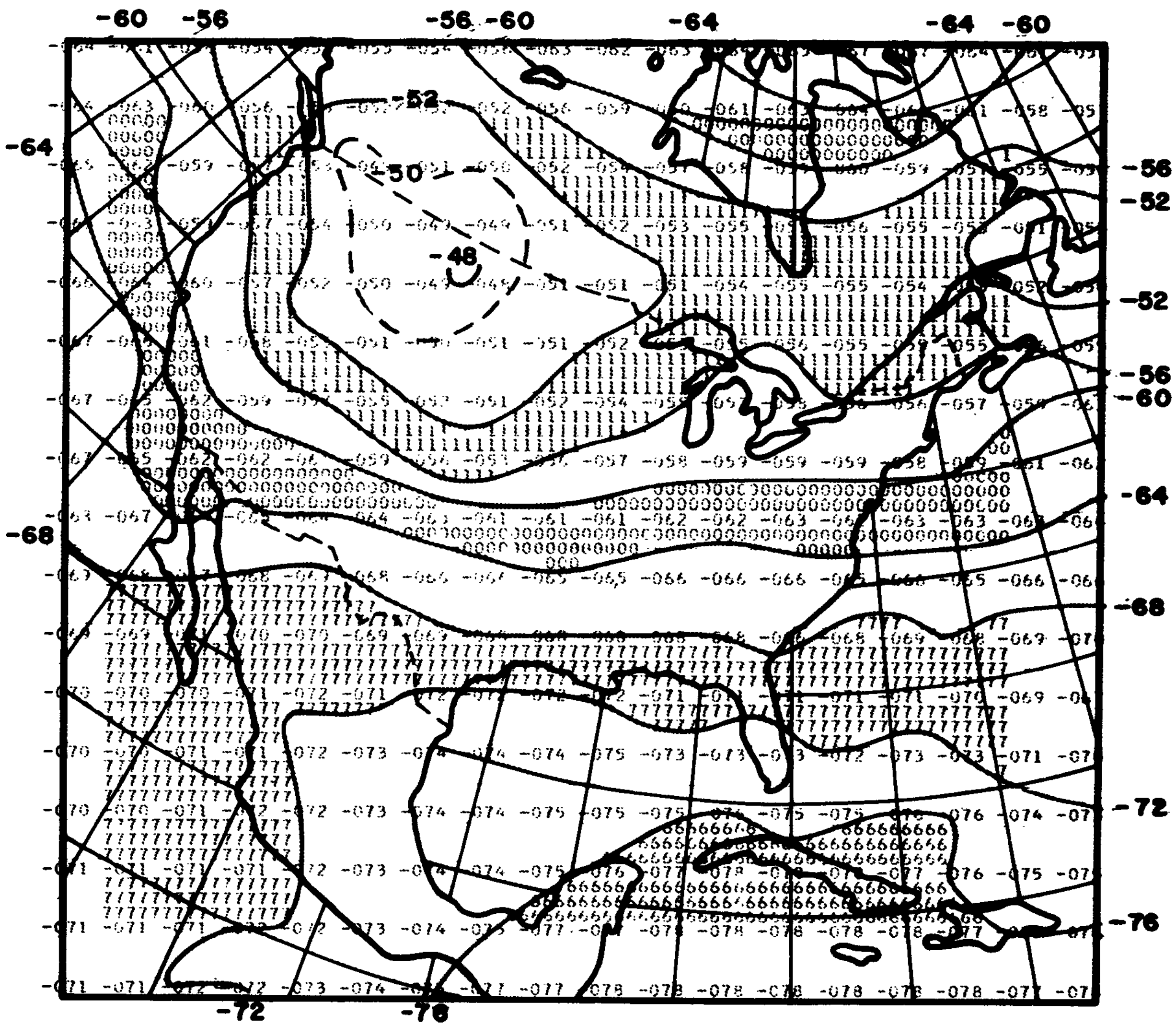


Fig. 4-17. 100-mb temperature analyses. (a) No smoothing performed.

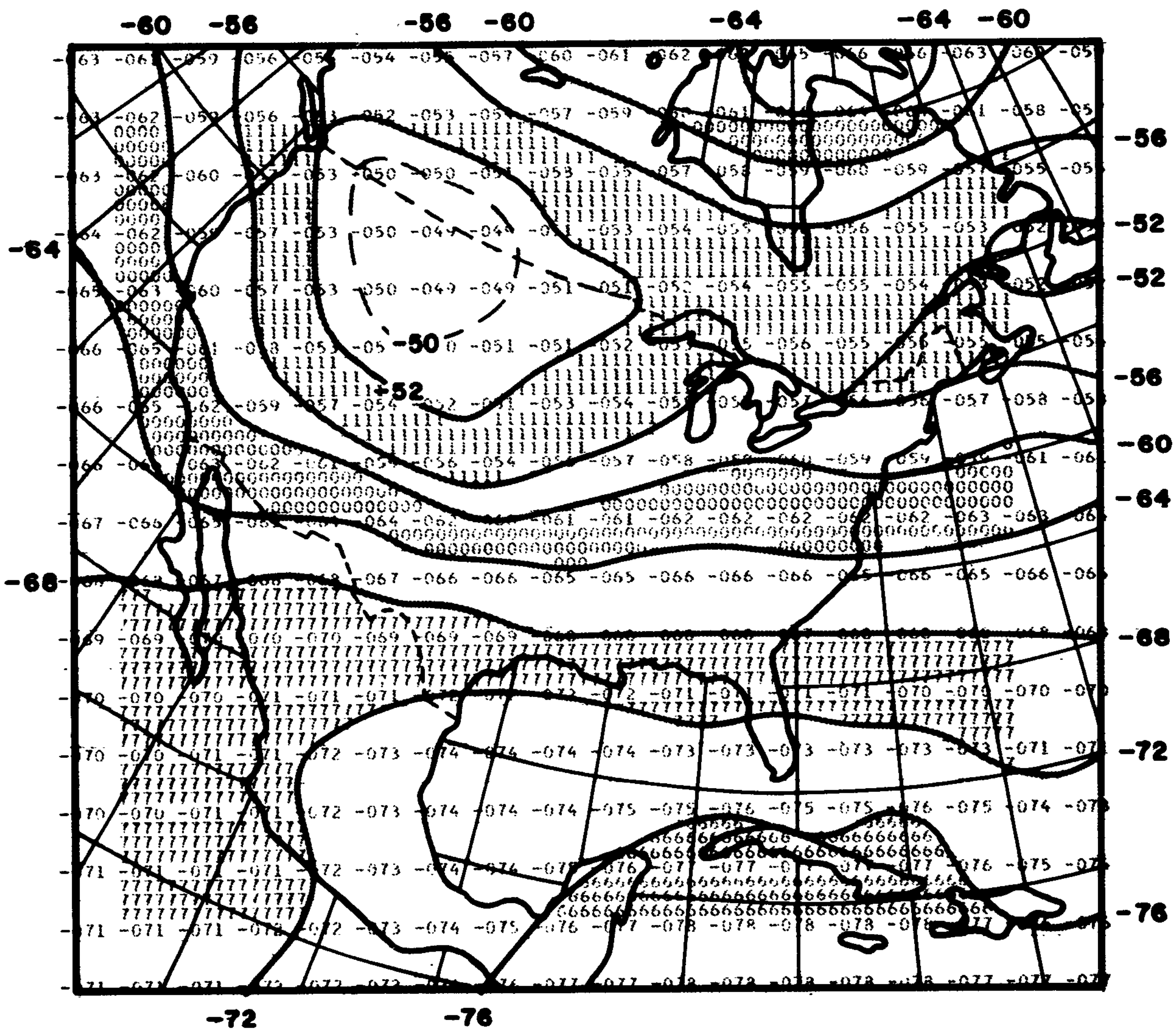


Fig. 4-17. (b) Smoothing performed after the last pass.

v-component, so the R's for the u-component should be somewhat larger than those for the v-component.

Table 4-6 contains a set of R's that has given satisfactory results.

4.4.2 Temperature Analysis and Verification

The variable parameters in the temperature analysis are R (the influence radius) and smoothing. Since the station density is exactly the same for the temperature observations as it is for the height observations, the same R's used by the NWP Unit for their 500-mb analyses, being as satisfactory as any other set that was tried, were used for our temperature analysis.

An experiment was run to determine the value of smoothing a temperature analysis at 100 mb. The verification statistics for five observation times showed little difference between smoothed and unsmoothed temperature analyses: the smoothed-analysis RMSE was 1.32°C, and the unsmoothed-analysis RMSE was 1.40°C. The actual analyses exhibited negligible differences, as may be seen from Fig. 4-17. It is recommended that the temperature field not be smoothed for a build-up analysis procedure.

4.5 Comparison of Build-up and Persistence as Initial Guess to 100-mb Analyses

Five consecutive sets of observations were analyzed by two methods. Each method was identical in every respect, with the exception of the specification of the initial-guess field. That is, the same set of analysis and verification stations and the same analysis parameters (i.e., R, number of passes, n, etc.) were employed in both instances. The initial-guess field for the first set of analyses was defined as the analysis of observations taken 12 hr earlier. For the second set of analyses, the first-guess field was defined as that derived by the application of the appropriate vertical-extrapolation equations, as outlined in Section 2.0. The verification results are summarized in Table 4-7.

It can be seen that, for both wind and temperature, the measure of error is smaller at each stage of the analysis for the build-up method. To test the significance

TABLE 4-7
VERIFICATION STATISTICS AT 100 mb
FROM PERSISTENCE AND BUILD-UP ANALYSIS PROCEDURES

Pass	Over-all vector-wind error, knots		Temperature RMSE, °C	
	Persistence	Build-up	Persistence	Build-up
0	16.21	12.70	2.3	1.9
1	13.25	11.00	2.0	1.7
2	11.81	10.13	1.7	1.5
3	11.34	9.79	1.5	1.3
4	—	—	1.4	1.2

of the indicated improvement, "Student's" t-test for paired comparisons [15] was performed on the five cases. The results of this test indicated that the difference in error between the two analysis methods was significant at less than the 5% level for the wind analysis and not significant at the 5% level for the temperature analysis.

This experiment should indicate the results to be expected in regions of relatively dense data. To complete the evaluation, it is necessary to conduct a similar experiment in which sparse-data regions of the hemisphere are simulated. Such an experiment has been attempted; however, the results were inconclusive because of a bias introduced by errors in the data furnished TRC.

5.0 SUMMARY AND CONCLUSIONS

Testing of vertical-extrapolation regression equations derived from mid-season radiosonde data on independent data from other midseason months yielded excellent results. These equations should be useful for specifying good initial-guess fields of height and temperature for a build-up objective-analysis procedure.

Tests of the equations with data from the months on each side of each mid-season month revealed that only about 5% of the equations produced errors large enough to warrant new equations. Two-thirds of these 5% pertained to months in spring or fall (transitional seasons). The vertical-extrapolation equations developed for a midseason month appear to be characteristically stable for the other months of the season.

For the 200–100-mb extrapolation interval, a vertical-extrapolation regression equation that uses present and past data was tested against an equation (developed by the Navy) that uses only present data. The equation that uses present and past (12-hr) data gave significantly better results (as determined by a "Student's" t-test) on independent data, demonstrating the value of past 12-hr information.

Limited developmental testing of the build-up objective-analysis procedure (incorporating the vertical-extrapolation equations) indicated the following.

(a) Varying the set of R's (the influence radii) within reasonable limits in any of the three objective analyses (height, temperature, wind) did not result in significantly changed verification statistics. The set of R's used by the NWP Unit in their 500-mb analyses gave results as good as any other set tried.

(b) Wind observations are, in general, more reliable than height observations, and wind observations should be weighted more heavily than height observations in the correction equation for heights at gridpoints. A wind-to-height weighting ratio of 4:1 is recommended for height analyses in the middle troposphere, and this ratio should be increased to at least 16:1 at 100 mb. The ratio at 100 mb is dependent on the geographic area of the analysis and the compatibility of radiosonde stations in that area. For North America, where the data are dense and the compatibility of radiosonde instruments is high, a 4:1 ratio was found to give better verification statistics than a 32:1 ratio. For hemispheric analyses, on the other hand, Teweles [13], after considerable experimentation, suggested the 32:1 ratio. Incompatibility of radiosonde instruments and the variation in data density over the entire hemisphere argue for the use of a 32:1 ratio.

(c) If the objective is a stratospheric analysis at the top of the build-up, heights need not be smoothed at all constant-pressure surfaces but only at the stratospheric levels and at two (or more) levels below 100 mb (and at any other level that may be of particular interest).

(d) Smoothing does not appear to be necessary to any temperature analysis.

A comparison test was performed on a North American grid to evaluate the relative accuracy of 100-mb wind and temperature analyses as obtained from two different types of initial-guess fields. One initial-guess field was given by 12-hr persistence, and the other was generated by the build-up analysis, using vertical-extrapolation equations. Results of the test, as determined from the areal-mean-error verification statistics, indicated that the build-up procedure produced wind RMSEs that were significantly lower than those given by using persistence as an initial guess. "Student's" t-test for paired comparisons was applied to the differences in the RMSEs and indicated the build-up errors to be significantly lower at the 5% level. For temperature, the build-up procedure produced lower errors than persistence, but the difference was not significant at the 5% level.

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APPENDIX A. STATIONS USED IN SCREENING-REGRESSION EXPERIMENTS

Latitude 0–25°N

Block	Station	Deg. lat.	Deg. long.
72	201	24.55N	81.80W
76	644	20.97N	89.63W
78	118	21.47N	71.13W
78	325	23.15N	82.35W
78	367	19.90N	75.15W
78	397	17.93N	76.78W
78	501	17.40N	83.93W
78	526	18.45N	66.10W
78	866	18.03N	63.10W
78	967	10.68N	61.62W
78	988	12.18N	68.98W
91	115	24.78N	141.33E
91	217	13.55N	144.83E
91	245	19.28N	166.65E
91	250	11.33N	162.33E
91	275	16.73N	169.52W
91	285	19.73N	155.07W
91	408	7.35N	134.48E
91	413	9.52N	138.13E

Latitude 25–35°N

Block	Station	Deg. lat.	Deg. long.
47	931	26.35N	127.75E
60	119	34.30N	6.60W
62	011	32.90N	13.28E
72	208	32.90N	80.00W
72	226	32.30N	86.40W
72	232	28.98N	89.37W
72	235	32.33N	90.22W
72	240	30.22N	93.15W
72	250	25.92N	97.47W
72	259	32.83N	97.05W
72	261	29.33N	100.88W
72	270	31.80N	106.40W
72	290	32.73N	117.17W
72	340	34.73N	92.23W
74	794	28.47N	80.55W
78	016	32.37N	64.83W
91	066	28.22N	177.37W
Ship	4YN	30.00N	140.00W
Ship	Victor	34.00N	164.00E

Latitude 35–45°N

Block	Station	Deg. lat.	Deg. long.
08	159	41.68N	1.07W
08	509	38.75N	27.08W
72	308	36.88N	76.20W
72	327	36.12N	86.68W
72	363	35.23N	101.70W
72	405	38.85N	77.03W
72	429	39.90N	84.20W
72	445	38.97N	92.37W
72	451	37.77N	99.97W
72	476	39.10N	108.53W
72	493	37.73N	122.20W
72	506	41.25N	70.07W
72	518	42.75N	73.80W
72	553	41.37N	96.02W
72	572	40.77N	111.98W
72	576	42.80N	108.72W
72	583	40.90N	117.80W
72	597	42.38N	122.87W
72	662	44.20N	103.05W
Ship	4YD	44.00N	41.00W

Latitude 45–55°N

Block	Station	Deg. lat.	Deg. long.
07	170	48.07N	5.03E
07	354	46.87N	1.73E
10	610	49.95N	6.57E
70	414	52.72N	174.10E
70	454	51.88N	176.65W
72	655	45.58N	94.18W
72	712	46.87N	68.02W
72	764	46.77N	100.75W
72	775	47.50N	111.35W
72	798	48.80N	124.73W
72	807	47.20N	54.00W
72	811	50.22N	66.27W
72	816	53.32N	60.42W
72	836	51.27N	80.65W
72	848	53.83N	89.87W
72	879	53.57N	113.52W
Ship	4YC	52.80N	33.50W

Latitude 55–65°N

Block	Station	Deg. lat.	Deg. long.
04	018	63.98N	22.63W
04	270	61.18N	45.42W
70	231	62.97N	115.62W
70	261	64.82N	147.87W
70	308	57.15N	170.22W
70	350	57.75N	152.52W
70	361	59.52N	138.67W
72	906	58.10N	68.43W
72	907	58.45N	78.13W
72	909	63.75N	68.55W
72	913	58.75N	94.07W
72	926	64.30N	96.00W
72	934	60.02N	111.97W
72	945	58.83N	122.58W
72	964	60.72N	135.07W
Ship	4YB	56.50N	51.00W

Latitude 65–90°N

Block	Station	Deg. lat.	Deg. long.
04	202	76.52N	68.83W
70	026	71.30N	156.78W
70	086	70.12N	143.67W
70	133	66.87N	162.63W
70	273	61.17N	149.98W
70	326	58.68N	156.65W
72	917	80.00N	85.93W
72	924	74.72N	94.98W
72	938	67.78N	115.25W
72	968	68.23N	135.00W
74	043	65.30N	126.85W
74	051	72.00N	124.50W
74	072	76.23N	119.33W
74	074	78.78N	103.53W
74	082	82.50N	62.33W
74	090	70.45N	68.55W

APPENDIX B. VERTICAL-EXTRAPOLATION EQUATIONS *

B.1 TRC Equations, for 500-100 mb

B.1.1 January

B.1.1.1 0–25°N

400 mb $Z_0 = 706.59 + 0.93076\,(500Z_0) + 2.0571\,(500T_0)$

400 mb $T_0 = -309.64 + 0.52294\,(400Z_0) - 0.52294\,(500Z_0) - 0.39719\,(500T_0) + 0.22918\,(400T_{-12})$

300 mb $Z_0 = 676.43 + 1.6800\,(500T_0) + 1.1572\,(500Z_0) + 0.61120\,(300Z_{-12}) - 0.86315\,(500Z_{-12})$

300 mb $Z_0 = 984.64 + 0.90022\,(400Z_0) + 2.9143\,(400T_0)$

300 mb $T_0 = -197.35 + 0.527135\,(300T_{-12}) + 0.14444\,(300Z_0) - 0.14444\,(500Z_0) - 0.275125\,(500T_{-12})$

300 mb $T_0 = -198.41 + 0.25785\,(300Z_0) - 0.25785\,(400Z_0) + 0.46377\,(300T_{-12}) - 0.22293\,(400T_{-12})$

250 mb $Z_0 = 628.86 + 0.95084\,(300Z_0) + 1.8342\,(300T_0)$

250 mb $T_0 = -214.03 + 0.34689\,(250Z_0) - 0.333838\,(300Z_0) + 0.47219\,(250T_{-12}) - 0.21443\,(300T_{-12})$

200 mb $Z_0 = 731.60 + 0.95459\,(250Z_0) + 2.0219\,(250T_0)$

200 mb $T_0 = -405.87 + 0.67632\,(200Z_0) - 0.67632\,(250Z_0) - 0.60640\,(250T_0)$

150 mb $Z_0 = 1065.2 + 0.91181\,(200Z_0) + 2.1714\,(200T_0)$

150 mb $T_0 = -357.65 + 0.24019\,(150T_{-12}) + 0.46029\,(150Z_0) - 0.46029\,(200Z_0) - 0.67665\,(200T_0)$

100 mb $Z_0 = 1200.9 + 0.85706\,(150Z_0) + 0.41905\,(100Z_{-12}) - 0.41905\,(150Z_{-12}) + 1.25420\,(150T_0)$

100 mb $T_0 = -153.02 + 0.14356\,(100Z_0) - 0.14356\,(150Z_0) + 0.47913\,(100T_{-12})$

B.1.1.2 25–35°N

400 mb $Z_0 = 631.18 + 0.96996\,(500Z_0) + 2.2115\,(500T_0)$

400 mb $T_0 = -358.96 + 0.60341\,(400Z_0) - 0.60341\,(500Z_0) - 0.36165\,(500T_0)$

*Units for all equations are degrees centigrade or tens of feet, as appropriate.

300 mb $Z_0 = 899.29 + 0.93758\,(500Z_0) + 3.1139\,(500T_0) + 0.38847\,(300Z_{-12})$
$- 0.38847\,(500Z_{-12})$

300 mb $Z_0 = 819.14 + 0.96470\,(400Z_0) + 2.7277\,(400T_0)$

300 mb $T_0 = - 339.35 + 0.24933\,(300Z_0) - 0.24933\,(500Z_0) - 0.58345\,(500T_0)$
$+ 0.25733\,(300T_{-12})$

300 mb $T_0 = - 374.62 + 0.49173\,(300Z_0) - 0.49173\,(400Z_0) - 0.61178\,(400T_0)$
$+ 0.19677\,(300T_{-12})$

250 mb $Z_0 = 592.55 + 0.96311\,(300Z_0) + 1.9402\,(300T_0)$

250 mb $T_0 = - 413.03 + 0.85703\,(250Z_0) - 0.85703\,(300Z_0) - 0.70181\,(300T_0)$
$+ 0.15055\,(250T_{-12})$

200 mb $Z_0 = 788.96 + 0.93999\,(250Z_0) + 2.1985\,(250T_0)$

200 mb $T_0 = - 421.78 + 0.71018\,(200Z_0) - 0.71018\,(250Z_0) - 0.81701\,(250T_0)$
$+ 0.17457\,(200T_{-12})$

150 mb $Z_0 = 795.04 + 0.93229\,(200Z_0) + 1.5689\,(200T_0) + 0.26118\,(150Z_{-12})$
$- 0.26118\,(200Z_{-12})$

150 mb $T_0 = - 224.03 + 0.36425\,(150Z_0) - 0.38359\,(200Z_0) - 0.40238\,(200T_0)$

100 mb $Z_0 = 1378.7 + 0.85271\,(150Z_0) + 1.3687\,(150T_0) + 0.23046\,(100Z_{-12})$
$- 0.23046\,(150Z_{-12})$

100 mb $T_0 = - 147.39 - 0.241283\,(150Z_0) + 0.21920\,(100Z_0) - 0.28763\,(150T_0)$
$+ 0.23347\,(100T_{-12})$

B.1.1.3 35–45°N

400 mb $Z_0 = 612.98 + 0.97849\,(500Z_0) + 2.1177\,(500T_0)$

400 mb $T_0 = - 356.61 + 0.59834\,(400Z_0) - 0.59834\,(500Z_0) - 0.36285\,(500T_0)$

300 mb $Z_0 = 1036.6 + 0.94251\,(500Z_0) + 3.2431\,(500T_0) + 0.26534\,(300Z_{-12})$
$- 0.26534\,(500Z_{-12})$

300 mb $Z_0 = 706.65 + 0.95589\,(400Z_0) + 2.2713\,(400T_0) + 0.18079\,(300Z_{-12})$
$- 0.18079\,(400Z_{-12})$

300 mb $T_0 = - 331.61 + 0.24178\,(300Z_0) - 0.24178\,(500Z_0) - 0.60631\,(500T_0)$
$+ 0.25126\,(300T_{-12})$

300 mb $T_0 = -\ 435.68 + 0.57261(300Z_0) - 0.57261(400Z_0) - 0.79941(400T_0)$
$+ 0.13975(300T_{-12})$

250 mb $Z_0 = 589.11 + 0.96187(300Z_0) + 1.8036(300T_0)$

250 mb $T_0 = -\ 520.20 + 1.0741(250Z_0) - 1.0741(300Z_0) - 1.0116(300T_0)$

200 mb $Z_0 = 653.35 + 0.94888(250Z_0) + 1.7632(250T_0) + 0.17349(200Z_{-12})$
$- 0.17349(250Z_{-12})$

200 mb $T_0 = -\ 235.39 + 0.45738(200Z_0) - 0.468919(250Z_0) + 0.23235(200T_{-12})$
$- 0.32903(250T_0)$

150 mb $Z_0 = 572.78 + 0.86206(200Z_0) + 1.3483(200T_0) + 0.35193(150Z_{-12})$
$- 0.24194(200Z_{-12})$

150 mb $T_0 = -\ 185.58 + 0.28729(150Z_0) - 0.299338(200Z_0) - 0.22239(200T_0)$
$+ 0.16028(150T_{-12})$

100 mb $Z_0 = 774.04 + 0.82312(150Z_0) + 1.3470(150T_0) + 0.44376(100Z_{-12})$
$- 0.31899(150Z_{-12})$

100 mb $T_0 = -\ 317.44 + 0.29877(100Z_0) - 0.29877(150Z_0) - 0.40542(150T_0)$
$+ 0.26414(100T_{-12})$

<u>B.1.1.4 45–55°N</u>

400 mb $Z_0 = 583.19 + 0.99329(500Z_0) + 2.0240(500T_0)$

400 mb $T_0 = -\ 392.63 + 0.66063(400Z_0) - 0.66063(500Z_0) - 0.50001(500T_0)$

300 mb $Z_0 = 983.89 + 0.97663(500Z_0) + 2.9589(500T_0) + 0.24943(300Z_{-12})$
$- 0.24943(500Z_{-12})$

300 mb $Z_0 = 698.53 + 0.96027(400Z_0) + 2.1959(400T_0) + 0.17041(300Z_{-12})$
$- 0.17041(400Z_{-12})$

300 mb $T_0 = -\ 377.28 + 0.22189(300T_{-12}) + 0.27573(300Z_0) - 0.27573(500Z_0)$
$- 0.78291(500T_0)$

300 mb $T_0 = -\ 459.29 + 0.60299(300Z_0) - 0.60299(400Z_0) - 0.90127(400T_0)$
$+ 0.13064(300T_{-12})$

250 mb $Z_0 = 18.857 + 1.0106(300Z_0) + 0.87163(250Z_{-12}) - 0.87163(300Z_{-12})$

250 mb $T_0 = -\ 5.8706 + 0.20380\,(250T_{-12}) + 0.46161\,(300T_0) - 0.232416\,(300Z_0)$
$+ 0.20080\,(250Z_0)$

200 mb $Z_0 = 32.924 + 0.90456\,(250Z_0) + 0.83179\,(200Z_{-12}) - 0.71065\,(250Z_{-12})$
$+ 0.70388\,(250T_0)$

200 mb $T_0 = -\ 9.9353 + 0.30375\,(200T_{-12}) + 0.30589\,(250T_0) + 0.14406\,(200Z_0)$
$- 0.168146\,(250Z_0)$

150 mb $Z_0 = 458.71 + 0.91638\,(200Z_0) + 1.6339\,(200T_0) + 0.34198\,(150Z_{-12})$
$- 0.25056\,(200Z_{-12})$

150 mb $T_0 = -\ 321.72 + 0.41902\,(150Z_0) - 0.41902\,(200Z_0) - 0.38313\,(200T_0)$
$+ 0.12514\,(150T_{-12})$

100 mb $Z_0 = 647.23 + 1.0036\,(150Z_0) + 2.1947\,(150T_0) + 0.36066\,(100Z_{-12})$
$- 0.36066\,(150Z_{-12})$

100 mb $T_0 = -\ 295.05 + 0.27568\,(100Z_0) - 0.27568\,(150Z_0) + 0.25378\,(100T_{-12})$
$- 0.34876\,(150T_0)$

B.1.1.5 55–65°N

400 mb $Z_0 = 602.16 + 0.98297\,(500Z_0) + 2.0666\,(500T_0)$

400 mb $T_0 = -\ 373.77 + 0.62642\,(400Z_0) - 0.62642\,(500Z_0) - 0.44891\,(500T_0)$

300 mb $Z_0 = 909.87 + 0.96081\,(500Z_0) + 2.6729\,(500T_0) + 0.33060\,(300Z_{-12})$
$- 0.33060\,(500Z_{-12})$

300 mb $Z_0 = 625.64 + 0.96621\,(400Z_0) + 1.9379\,(400T_0) + 0.24842\,(300Z_{-12})$
$- 0.24842\,(400Z_{-12})$

300 mb $T_0 = -\ 310.23 + 0.36138\,(300T_{-12}) + 0.22666\,(300Z_0) - 0.22666\,(500Z_0)$
$- 0.63937\,(500T_0)$

300 mb $T_0 = -\ 444.93 + 0.58513\,(300Z_0) - 0.58513\,(400Z_0) - 0.88524\,(400T_0)$
$+ 0.18519\,(300T_{-12})$

250 mb $Z_0 = 447.70 + 0.97127\,(300Z_0) + 1.5279\,(300T_0) + 0.25606\,(250Z_{-12})$
$- 0.25606\,(300Z_{-12})$

250 mb $T_0 = -\ 503.12 + 1.0475\,(250Z_0) - 1.0475\,(300Z_0) - 0.87663\,(300T_0)$

$$200\ \text{mb} \quad Z_0 = 375.34 + 0.91231\,(250Z_0) + 1.4037\,(250T_0) + 0.399646\,(200Z_{-12}) - 0.31708\,(250Z_{-12})$$

$$200\ \text{mb} \quad T_0 = -363.01 + 0.61512\,(200Z_0) - 0.61512\,(250Z_0) - 0.52050\,(250T_0) + 0.14714\,(200T_{-12})$$

$$150\ \text{mb} \quad Z_0 = 407.21 + 0.93279\,(200Z_0) + 1.6998\,(200T_0) + 0.334942\,(150Z_{-12}) - 0.24387\,(200Z_{-12})$$

$$150\ \text{mb} \quad T_0 = -209.58 + 0.27673\,(150Z_0) - 0.27673\,(200Z_0) + 0.425375\,(150T_{-12}) - 0.199655\,(200T_{-12})$$

$$100\ \text{mb} \quad Z_0 = 649.40 + 0.3378293\,(100Z_{-12}) + 1.0090\,(150Z_0) + 2.5856\,(150T_0) - 0.33435\,(150Z_{-12})$$

$$100\ \text{mb} \quad T_0 = -149.51 + 0.14097\,(100Z_0) - 0.14097\,(150Z_0) + 0.47163\,(100T_{-12})$$

B.1.1.6 65–90°N

$$400\ \text{mb} \quad Z_0 = 605.56 + 0.98132\,(500Z_0) + 2.0803\,(500T_0)$$

$$400\ \text{mb} \quad T_0 = -389.46 + 0.65392\,(400Z_0) - 0.65392\,(500Z_0) - 0.50034\,(500T_0)$$

$$300\ \text{mb} \quad Z_0 = 867.97 + 0.96473\,(500Z_0) + 2.5628\,(500T_0) + 0.35792\,(300Z_{-12}) - 0.35792\,(500Z_{-12})$$

$$300\ \text{mb} \quad Z_0 = 635.27 + 0.96765\,(400Z_0) + 1.9720\,(400T_0) + 0.22945\,(300Z_{-12}) - 0.22945\,(400Z_{-12})$$

$$300\ \text{mb} \quad T_0 = -338.38 + 0.33706\,(300T_{-12}) + 0.24892\,(300Z_0) - 0.24892\,(500Z_0) - 0.68280\,(500T_0)$$

$$300\ \text{mb} \quad T_0 = -452.77 + 0.59744\,(300Z_0) - 0.59744\,(400Z_0) - 0.87503\,(400T_0) + 0.17470\,(300T_{-12})$$

$$250\ \text{mb} \quad Z_0 = 414.74 + 0.97438\,(300Z_0) + 1.4583\,(300T_0) + 0.31010\,(250Z_{-12}) - 0.31010\,(300Z_{-12})$$

$$250\ \text{mb} \quad T_0 = -514.61 + 1.0745\,(250Z_0) - 1.0745\,(300Z_0) - 0.89574\,(300T_0)$$

$$200\ \text{mb} \quad Z_0 = 431.24 + 0.99334\,(250Z_0) + 1.7106\,(250T_0) + 0.32688\,(200Z_{-12}) - 0.32688\,(250Z_{-12})$$

$$200\ \text{mb} \quad T_0 = -368.27 + 0.62636\,(200Z_0) - 0.62636\,(250Z_0) - 0.57128\,(250T_0) + 0.19900\,(200T_{-12})$$

150 mb $Z_0 = 421.31 + 1.0239\,(200Z_0) + 1.8120\,(200T_0) + 0.32143\,(150Z_{-12}) - 0.32143\,(200Z_{-12})$

150 mb $T_0 = -\,392.57 + 0.47331\,(150Z_0) - 0.46425\,(200Z_0) - 0.33403\,(200T_0)$

100 mb $Z_0 = 558.31 - 0.446846\,(100Z_{-12}) + 1.0444\,(150Z_0) + 2.3500\,(150T_0) - 0.42155\,(150Z_{-12})$

100 mb $T_0 = -\,447.15 + 0.42088\,(100Z_0) - 0.42088\,(150Z_0) - 0.61475\,(150T_0)$

B.1.2 April

B.1.2.1 0–25°N

400 mb $Z_0 = 815.63 + 0.87563\,(500Z_0) + 2.4202\,(500T_0)$

400 mb $T_0 = -\,285.00 - 0.48136\,(500Z_0) - 0.24025\,(500T_0) + 0.23962\,(400T_{-12}) + 0.48136\,(400Z_0)$

300 mb $Z_0 = 883.28 + 2.9994\,(500T_0) + 0.90680\,(500Z_0) + 0.45035\,(300Z_{-12}) - 0.45035\,(500Z_{-12})$

300 mb $Z_0 = 1120.8 + 0.84628\,(400Z_0) + 3.0236\,(400T_0)$

300 mb $T_0 = -\,219.00 - 0.15830\,(500Z_0) + 0.392115\,(300T_{-12}) - 0.246665\,(500T_{-12}) + 0.15830\,(300Z_0)$

300 mb $T_0 = -\,187.83 - 0.23942\,(400Z_0) + 0.28389\,(300T_{-12}) + 0.23942\,(300Z_0)$

250 mb $Z_0 = 893.50 + 0.87126\,(300Z_0) + 2.2120\,(300T_0)$

250 mb $T_0 = -\,96.865 - 0.18348\,(300Z_0) + 0.33633\,(300T_0) + 0.241864\,(250T_{-12}) + 0.18348\,(250Z_0)$

200 mb $Z_0 = 906.75 + 0.91056\,(250Z_0) + 2.4416\,(250T_0)$

200 mb $T_0 = -\,363.48 - 0.60307\,(250Z_0) - 0.43571\,(250T_0) + 0.60307\,(200Z_0)$

150 mb $Z_0 = 1218.3 + 0.88270\,(200Z_0) + 2.8453\,(200T_0)$

150 mb $T_0 = -\,455.60 - 0.58532\,(200Z_0) - 0.82914\,(200T_0) + 0.58532\,(150Z_0)$

100 mb $Z_0 = 1672.5 + 0.78825\,(150Z_0) + 1.4079\,(150T_0) + 0.23681\,(100Z_{-12}) - 0.23681\,(150Z_{-12})$

100 mb $T_0 = -\,2.2489 - 0.08623\,(150Z_0) + 0.40531\,(100T_{-12}) + 0.11484\,(100Z_0)$

B.1.2.2 25–35°N

400 mb $Z_0 = 632.86 + 0.96998\,(500Z_0) + 2.3071\,(500T_0)$

400 mb $T_0 = -\ 240.91 - 0.40183\,(500Z_0) + 0.13241\,(400T_{-12}) + 0.40188\,(400Z_0)$

300 mb $Z_0 = 960.60 + 0.96139\,(500Z_0) + 3.6596\,(500T_0) + 0.30711\,(300Z_{-12})$
$- 0.30711\,(500Z_{-12})$

300 mb $Z_0 = 809.52 + 0.96985\,(400Z_0) + 2.8255\,(400T_0)$

300 mb $T_0 = -\ 309.87 - 0.22492\,(500Z_0) - 0.37600\,(500T_0) + 0.18817\,(300T_{-12})$
$+ 0.22492\,(300Z_0)$

300 mb $T_0 = -\ 401.92 - 0.52322\,(400Z_0) - 0.54745\,(400T_0) + 0.52322\,(300Z_0)$

250 mb $Z_0 = 596.65 + 0.96130\,(300Z_0) + 1.8999\,(300T_0)$

250 mb $T_0 = -\ 433.55 - 0.89689\,(300Z_0) - 0.62931\,(300T_0) + 0.89689\,(250Z_0)$

200 mb $Z_0 = 820.61 + 0.93291\,(250Z_0) + 2.3373\,(250T_0)$

200 mb $T_0 = -\ 525.65 - 0.88733\,(250Z_0) - 1.0234\,(250T_0) + 0.88733\,(200Z_0)$

150 mb $Z_0 = 926.05 + 0.90937\,(200Z_0) + 1{,}8297\,(200T_0) + 0.21785\,(150Z_{-12})$
$- 0.21785\,(200Z_{-12})$

150 mb $T_0 = -\ 239.56 - 0.393638\,(200Z_0) - 0.47937\,(200T_0) + 0.13365\,(150T_{-12})$
$+ 0.37750\,(150Z_0)$

100 mb $Z_0 = 739.05 + 0.81544\,(150Z_0) + 1.0642\,(150T_0) + 0.51238\,(100Z_{-12})$
$- 0.38861\,(150Z_{-12})$

100 mb $T_0 = -\ 214.98 - 0.20207\,(150Z_0) - 0.20973\,(150T_0) + 0.43163\,(100T_{-12})$
$+ 0.20207\,(100Z_0)$

B.1.2.3 35–45°N

400 mb $Z_0 = 616.57 + 0.97733\,(500Z_0) + 2.1962\,(500T_0)$

400 mb $T_0 = -\ 231.14 - 0.38392\,(500Z_0) + 0.13851\,(400T_{-12}) + 0.38392\,(400Z_0)$

300 mb $Z_0 = 894.67 + 0.99456\,(500Z_0) + 3.0219\,(500T_0) + 0.30064\,(300Z_{-12})$
$- 0.30064\,(500Z_{-12})$

300 mb $Z_0 = 825.63 + 0.95968\,(400Z_0) + 2.5826\,(400T_0)$

$$300\text{ mb}\quad T_0 = -399.48 - 0.29395(500Z_0) - 0.81287(500T_0) + 0.19631(300T_{-12}) + 0.29395(300Z_0)$$

$$300\text{ mb}\quad T_0 = -371.55 - 0.48501(400Z_0) - 0.62055(400T_0) + 0.17766(300T_{-12}) + 0.48501(300Z_0)$$

$$250\text{ mb}\quad Z_0 = 612.07 + 0.95534(300Z_0) + 1.8600(300T_0)$$

$$250\text{ mb}\quad T_0 = -528.14 - 1.0919(300Z_0) - 1.0318(300T_0) + 1.0919(250Z_0)$$

$$200\text{ mb}\quad Z_0 = 867.73 + 0.91451(250Z_0) + 2.0612(250T_0)$$

$$200\text{ mb}\quad T_0 = -525.97 - 0.88448(250Z_0) - 1.0571(250T_0) + 0.88448(200Z_0)$$

$$150\text{ mb}\quad Z_0 = 916.55 + 0.91271(200Z_0) + 1.6037(200T_0) + 0.18821(150Z_{-12}) - 0.18821(200Z_{-12})$$

$$150\text{ mb}\quad T_0 = -223.62 - 0.37343(200Z_0) - 0.32115(200T_0) + 0.35678(150Z_0)$$

$$100\text{ mb}\quad Z_0 = 424.07 + 0.78057(150Z_0) + 1.0429(150T_0) + 0.61291(100Z_{-12}) - 0.40261(150Z_{-12})$$

$$100\text{ mb}\quad T_0 = -223.39 - 0.20925(150Z_0) - 0.19717(150T_0) + 0.37145(100T_{-12}) + 0.20925(100Z_0)$$

B.1.2.4 45–55°N

$$400\text{ mb}\quad Z_0 = 595.19 + 0.98740(500Z_0) + 2.0838(500T_0)$$

$$400\text{ mb}\quad T_0 = -350.91 - 0.58825(500Z_0) - 0.34646(500T_0) + 0.58825(400Z_0)$$

$$300\text{ mb}\quad Z_0 = 993.16 + 0.96966(500Z_0) + 3.0018(500T_0) + 0.25408(300Z_{-12}) - 0.25408(500Z_{-12})$$

$$300\text{ mb}\quad Z_0 = 848.13 + 0.94668(400Z_0) + 2.4260(400T_0)$$

$$300\text{ mb}\quad T_0 = -354.80 + 0.25815(300Z_0) - 0.25815(500Z_0) - 0.79333(500T_0) + 0.25774(300T_{-12})$$

$$300\text{ mb}\quad T_0 = -427.46 - 0.55874(400Z_0) - 0.86039(400T_0) + 0.17012(300T_{-12}) + 0.55874(300Z_0)$$

$$250\text{ mb}\quad Z_0 = 655.12 + 0.93892(300Z_0) + 1.7682(300T_0)$$

$$250\text{ mb}\quad T_0 = -525.48 + 1.0845(250Z_0) - 1.0845(300Z_0) - 1.0390(300T_0)$$

$$200\text{ mb}\quad Z_0 = 854.43 + 0.91151(250Z_0) + 1.6549(250T_0)$$

200 mb $T_0 = -464.82 + 0.78173\,(200Z_0) - 0.78173\,(250Z_0) - 0.81851\,(250T_0)$

150 mb $Z_0 = 896.52 + 0.95176\,(200Z_0) + 1.9208\,(200T_0)$

150 mb $T_0 = -281.18 - 0.36303\,(200Z_0) - 0.26345\,(200T_0) + 0.12394\,(150T_{-12}) + 0.36303\,(150Z_0)$

100 mb $Z_0 = 885.48 + 0.84649\,(150Z_0) + 1.5778\,(150T_0) + 0.365949\,(100Z_{-12}) - 0.27128\,(150Z_{-12})$

100 mb $T_0 = -199.14 - 0.18391\,(150Z_0) + 0.41103\,(100T_{-12}) - 0.19316\,(150T_{-12}) + 0.18391\,(100Z_0)$

B.1.2.5 55–65°N

400 mb $Z_0 = 598.13 + 0.98638\,(500Z_0) + 2.1288\,(500T_0)$

400 mb $T_0 = -257.67 - 0.42527\,(500Z_0) + 0.42527\,(400Z_0)$

300 mb $Z_0 = 906.42 + 0.96076\,(500Z_0) + 2.7817\,(500T_0) + 0.33693\,(300Z_{-12}) - 0.33693\,(500Z_{-12})$

300 mb $Z_0 = 668.67 + 0.94384\,(400Z_0) + 2.0223\,(400T_0) + 0.26720\,(300Z_{-12}) - 0.26720\,(400Z_{-12})$

300 mb $T_0 = -339.06 + 0.24697\,(300Z_0) - 0.24697\,(500Z_0) - 0.79880\,(500T_0) + 0.33200\,(300T_{-12})$

300 mb $T_0 = -480.17 - 0.63012\,(400Z_0) - 1.0139\,(400T_0) + 0.13625\,(300T_{-12}) + 0.63012\,(300Z_0)$

250 mb $Z_0 = 642.20 + 0.94091\,(300Z_0) + 1.6371\,(300T_0)$

250 mb $T_0 = -480.82 - 0.98927\,(300Z_0) - 0.89260\,(300T_0) + 0.98927\,(250Z_0)$

200 mb $Z_0 = 743.49 + 0.94421\,(250Z_0) + 1.5948\,(250T_0)$

200 mb $T_0 = -395.31 - 0.66475\,(250Z_0) - 0.55102\,(250T_0) + 0.66475\,(200Z_0)$

150 mb $Z_0 = 799.77 + 0.98016\,(200Z_0) + 2.1219\,(200T_0)$

150 mb $T_0 = -211.34 + 0.27383\,(200Z_0) + 0.305215\,(150T_{-12}) - 0.156225\,(200T_{-12}) + 0.27383\,(150Z_0)$

100 mb $Z_0 = 963.81 + 0.94337\,(150Z_0) + 1.8865\,(150T_0) + 0.28279\,(100Z_{-12}) - 0.28279\,(150Z_{-12})$

100 mb $T_0 = -71.404 - 0.1064059\,(150Z_0) + 0.40428\,(100T_{-12}) + 0.096748\,(100Z_0)$

B.1.2.6 65–90°N

400 mb $Z_0 = 609.41 + 0.97852(500Z_0) + 2.0590(500T_0)$

400 mb $T_0 = -471.71 - 0.79801(500Z_0) - 0.79563(500T_0) + 0.79801(400Z_0)$

300 mb $Z_0 = 725.98 + 0.94652(500Z_0) + 1.9040(500T_0) + 0.49395(300Z_{-12}) - 0.49395(500Z_{-12})$

300 mb $Z_0 = 626.44 + 0.93500(400Z_0) + 1.8018(400T_0) + 0.35257(300Z_{-12}) - 0.35257(400Z_{-12})$

300 mb $T_0 = -326.71 - 0.2311103(500Z_0) - 0.81894(500T_0) + 0.34474(300T_{-12}) + 0.23308(300Z_0)$

300 mb $T_0 = -428.44 - 0.55586(400Z_0) - 0.92731(400T_0) + 0.17313(300T_{-12}) + 0.55586(300Z_0)$

250 mb $Z_0 = 596.87 + 0.95509(300Z_0) + 1.5431(300T_0)$

250 mb $T_0 = -464.32 - 0.95773(300Z_0) - 0.80865(300T_0) + 0.95773(250Z_0)$

200 mb $Z_0 = 662.76 + 0.97083(250Z_0) + 1.7246(250T_0)$

200 mb $T_0 = -376.28 - 0.63434(250Z_0) - 0.46781(250T_0) + 0.63434(200Z_0)$

150 mb $Z_0 = 814.12 + 0.97731(200Z_0) + 2.1865(200T_0)$

150 mb $T_0 = -318.99 - 0.42124(200Z_0) - 0.34033(200T_0) + 0.15570(150T_{-12}) + 0.42124(150Z_0)$

100 mb $Z_0 = 728.40 + 0.95857(150Z_0) + 1.7110(150T_0) + 0.46780(100Z_{-12}) - 0.46780(150Z_{-12})$

100 mb $T_0 = -79.792 - 0.1142054(150Z_0) + 0.44908(100T_{-12}) + 0.10534(100Z_0)$

B.1.3 July

B.1.3.1 0–25°N

300 mb $Z_0 = 1869.7 + 0.80469(500Z_0) + 3.0136(500T_0) + 0.17441(300Z_{-12}) - 0.40373(500Z_{-12})$

300 mb $T_0 = -244.51 - 0.17691(500Z_0) + 0.307235(300T_{-12}) - 0.166365(500T_{-12}) + 0.17691(300Z_0)$

250 mb $Z_0 = 1021.7 + 0.82945(300Z_0) + 2.0387(300T_0)$

250 mb $T_0 = -\ 57.322 - 0.10317\,(300Z_0) + 0.64580\,(300T_0) + 0.16236\,(250T_{-12})$
$+\ 0.10317\,(250Z_0)$

200 mb $Z_0 = 1221.5 + 0.82421\,(250Z_0) + 2.5376\,(250T_0)$

200 mb $T_0 = -\ 251.68 - 0.40912\,(250Z_0) + 0.40912\,(200Z_0)$

150 mb $Z_0 = 1529.3 + 0.80811\,(200Z_0) + 2.9565\,(200T_0)$

150 mb $T_0 = -\ 665.75 - 0.63957\,(200Z_0) - 1.2876\,(200T_0) + 0.67250\,(150Z_0)$

100 mb $Z_0 = 933.76 + 0.85394\,(150Z_0) + 0.67683\,(100Z_{-12}) - 0.67683\,(150Z_{-12})$

100 mb $T_0 = -\ 119.88 - 0.10633\,(150Z_0) + 0.50032\,(100T_{-12}) + 0.10633\,(100Z_0)$

<u>B.1.3.2 25–35°N</u>

300 mb $Z_0 = 726.53 + 1.0038\,(500Z_0) + 2.3720\,(500T_0) + 0.42381\,(300Z_{-12})$
$-\ 0.42381\,(500Z_{-12})$

300 mb $T_0 = -\ 208.38 - 0.14939\,(500Z_0) + 0.371545\,(300T_{-12}) - 0.225995\,(500T_{-12})$
$+\ 0.14939\,(300Z_0)$

250 mb $Z_0 = 781.63 + 0.90467\,(300Z_0) + 1.9867\,(300T_0)$

250 mb $T_0 = -\ 150.38 - 0.29403\,(300Z_0) + 0.31531\,(250T_{-12}) + 0.29403\,(250Z_0)$

200 mb $Z_0 = 889.39 + 0.91225\,(250Z_0) + 2.1325\,(250T_0)$

200 mb $T_0 = -\ 423.73 - 0.70808\,(250Z_0) - 0.66739\,(250T_0) + 0.70808\,(200Z_0)$

150 mb $Z_0 = 1337.5 = 0.85442\,(200Z_0) + 2.8475\,(200T_0)$

150 mb $T_0 = -\ 462.85 - 0.59311\,(200Z_0) - 0.89370\,(200T_0) + 0.59311\,(150Z_0)$

100 mb $Z_0 = 497.76 + 0.94345\,(150Z_0) + 0.70659\,(100Z_{-12}) - 0.70659\,(150Z_{-12})$

100 mb $T_0 = -\ 169.13 - 0.14842\,(150Z_0) - 0.25307\,(150T_0) + 0.50227\,(100T_{-12})$
$+\ 0.14842\,(100Z_0)$

<u>B.1.3.3 35–45°N</u>

300 mb $Z_0 = 847.16 + 0.96789\,(500Z_0) + 3.4309\,(500T_0) + 0.38817\,(300Z_{-12})$
$-\ 0.38817\,(500Z_{-12})$

300 mb $T_0 = -\ 372.81 - 0.27089\,(500Z_0) - 0.35466\,(500T_0) + 0.27089\,(300Z_0)$

250 mb $Z_0 = 622.67 + 0.95408\,(300Z_0) + 1.9574\,(300T_0)$

250 mb $T_0 = -\ 208.16 - 0.42348\,(300Z_0) + 0.21194\,(250T_{-12}) + 0.42348\,(250Z_0)$

$$200\text{ mb}\quad Z_0 = 849.64 + 0.92393\,(250Z_0) + 2.2085\,(250T_0)$$

$$200\text{ mb}\quad T_0 = -\,494.01 - 0.82225\,(250Z_0) - 1.0240\,(250T_0) + 0.82225\,(200Z_0)$$

$$150\text{ mb}\quad Z_0 = 1407.9 + 0.82718\,(200Z_0) + 2.0969\,(200T_0)$$

$$150\text{ mb}\quad T_0 = -\,355.14 - 0.45799\,(200Z_0) - 0.65922\,(200T_0) + 0.23149\,(150T_{-12}) + 0.45799\,(150Z_0)$$

$$100\text{ mb}\quad Z_0 = 492.97 + 0.76505\,(150Z_0) + 1.3464\,(150T_0) + 0.61936\,(100Z_{-12}) - 0.40620\,(150Z_{-12})$$

$$100\text{ mb}\quad T_0 = -\,134.84 - 0.12303\,(150Z_0) + 0.46319\,(100T_{-12}) + 0.12303\,(100Z_0)$$

B.1.3.4 45–55°N

$$300\text{ mb}\quad Z_0 = 1316.5 + 0.97715\,(500Z_0) + 4.7636\,(500T_0)$$

$$300\text{ mb}\quad T_0 = -\,425.59 - 0.31064\,(500Z_0) - 0.69662\,(500T_0) + 0.31064\,(300Z_0)$$

$$250\text{ mb}\quad Z_0 = 616.80 + 0.95413\,(300Z_0) + 1.8564\,(300T_0)$$

$$250\text{ mb}\quad T_0 = -\,514.49 - 1.0602\,(300Z_0) - 1.0252\,(300T_0) + 1.0602\,(250Z_0)$$

$$200\text{ mb}\quad Z_0 = 914.67 + 0.90037\,(250Z_0) + 1.8947\,(250T_0)$$

$$200\text{ mb}\quad T_0 = -\,345.11 - 0.646616\,(250Z_0) - 0.72702\,(250T_0) + 0.11790\,(200T_{-12}) + 0.63537\,(200Z_0)$$

$$150\text{ mb}\quad Z_0 = 1185.9 + 0.87478\,(200Z_0) + 1.5345\,(200T_0)$$

$$150\text{ mb}\quad T_0 = -\,194.32 - 0.375396\,(200Z_0) - 0.34041\,(200T_0) + 0.35238\,(150Z_0)$$

$$100\text{ mb}\quad Z_0 = 941.26 + 0.80547\,(150Z_0) + 1.5611\,(150T_0) + 0.37735\,(100Z_{-12}) - 0.25469\,(150Z_{-12})$$

$$100\text{ mb}\quad T_0 = -\,163.50 - 0.15029\,(150Z_0) + 0.34838\,(100T_{-12}) + 0.15029\,(100Z_0)$$

B.1.3.5 55–65°N

$$300\text{ mb}\quad Z_0 = 1303.3 + 0.98361\,(500Z_0) + 4.6744\,(500T_0)$$

$$300\text{ mb}\quad T_0 = -\,342.10 - 0.25104\,(500Z_0) - 0.69667\,(500T_0) - 0.29083\,(300T_{-12}) + 0.25104\,(300Z_0)$$

$$250\text{ mb}\quad Z_0 = 667.66 + 0.93693\,(300Z_0) + 1.8452\,(300T_0)$$

$$250\text{ mb}\quad T_0 = -\,484.25 - 1.0001\,(300Z_0) - 1.0449\,(300T_0) + 0.14462\,(250T_{-12}) + 1.0001\,(250Z_0)$$

200 mb $Z_0 = 991.66 + 0.87344\,(250Z_0) + 1.6035\,(250T_0)$

200 mb $T_0 = -\ 374.10 - 0.62516\,(250Z_0) - 0.66289\,(250T_0) + 0.14864\,(200T_{-12})$
$\quad + 0.62516\,(200Z_0)$

150 mb $Z_0 = 869.92 + 0.95889\,(200Z_0) + 1.7584\,(200T_0)$

150 mb $T_0 = -\ 294.43 - 0.37650\,(200Z_0) - 0.25674\,(200T_0) + 0.37650\,(150Z_0)$

100 mb $Z_0 = 733.90 + 0.89688\,(150Z_0) + 2.7989\,(150T_0) + 0.13696\,(100Z_{-12})$

100 mb $T_0 = -\ 93.496 - 0.080453\,(150Z_0) + 0.35023\,(150T_0) + 0.375615\,(100T_{-12})$
$\quad - 0.207775\,(150T_{-12}) + 0.080453\,(100Z_0)$

B.1.3.6 65–90°N

300 mb $Z_0 = 1110.4 + 0.94325\,(500Z_0) + 3.8614\,(500T_0) + 0.21206\,(300Z_{-12})$
$\quad - 0.21206\,(500Z_{-12})$

300 mb $T_0 = -\ 398.74 - 0.29542\,(500Z_0) - 0.987281\,(500T_0) + 0.32780\,(300T_{-12})$
$\quad + 0.29542\,(300Z_0)$

250 mb $Z_0 = 703.77 + 0.92276\,(300Z_0) + 1.7024\,(300T_0)$

250 mb $T_0 = -\ 451.46 - 0.92596\,(300Z_0) - 0.96343\,(300T_0) + 0.14414\,(250T_{-12})$
$\quad + 0.92596\,(250Z_0)$

200 mb $Z_0 = 1008.9 + 0.86339\,(250Z_0) + 1.2375\,(250T_0)$

200 mb $T_0 = -\ 310.26 - 0.51682\,(250Z_0) - 0.46979\,(250T_0) + 0.18578\,(200T_{-12})$
$\quad + 0.51682\,(200Z_0)$

150 mb $Z_0 = 850.21 + 0.96417\,(200Z_0) + 1.7373\,(200T_0)$

150 mb $T_0 = -\ 220.80 - 0.27929\,(200Z_0) + 0.27929\,(150Z_0)$

100 mb $Z_0 = 561.38 + 0.91608\,(150Z_0) + 3.0046\,(150T_0) + 0.15499\,(100Z_{-12})$

100 mb $T_0 = -\ 72.710 - 0.066889\,(150Z_0) + 0.40139\,(150T_0) + 0.51096\,(100T_{-12})$
$\quad - 0.21265\,(150T_{-12}) + 0.066889\,(100Z_0)$

B.1.4 October

B.1.4.1 0–25°N

400 mb $Z_0 = 749.46 + 0.90882\,(500Z_0) + 1.9588\,(500T_0)$

400 mb $T_0 = -\ 267.28 - 0.45034\,(500Z_0) - 0.22181\,(500T_0) + 0.24780\,(400T_{-12})$
$\quad + 0.45034\,(400Z_0)$

300 mb $Z_0 = 922.57 + 0.89896\,(500Z_0) + 2.6759\,(500T_0) + 0.43019\,(300Z_{-12})$
$- 0.43019\,(500Z_{-12})$

300 mb $Z_0 = 1199.5 + 0.81466\,(400Z_0) + 2.9930\,(400T_0)$

300 mb $T_0 = - 253.87 - 0.18387\,(500Z_0) - 0.21738\,(500T_0) + 0.29644\,(300T_{-12})$
$+ 0.18387\,(300Z_0)$

300 mb $T_0 = - 198.82 - 0.25477\,(400Z_0) + 0.26961\,(300T_{-12}) + 0.25477\,(300Z_0)$

250 mb $Z_0 = 980.13 + 0.84434\,(300Z_0) + 2.2405\,(300T_0)$

250 mb $T_0 = - 77.465 + 0.14500\,(250Z_0) - 0.14500\,(300Z_0) + 0.49616\,(300T_0)$
$+ 0.20815\,(250T_{-12})$

200 mb $Z_0 = 1183.6 + 0.83799\,(250Z_0) + 2.8257\,(250T_0)$

200 mb $T_0 = - 235.01 - 0.38991\,(250Z_0) + 0.303905\,(200T_{-12}) - 0.216295\,(250T_{-12})$
$+ 0.38991\,(200Z_0)$

150 mb $Z_0 = 1445.7 + 0.83093\,(200Z_0) + 3.1419\,(200T_0)$

150 mb $T_0 = - 413.31 - 0.54003\,(200Z_0) - 0.73712\,(200T_0) + 0.15879\,(150T_{-12})$
$+ 0.54003\,(150Z_0)$

100 mb $Z_0 = 1200.4 + 0.86289\,(150Z_0) + 1.4277\,(150T_0) + 0.40167\,(100Z_{-12})$
$- 0.40167\,(150Z_{-12})$

100 mb $T_0 = - 104.45 + 0.096897\,(100Z_0) - 0.096897\,(150Z_0) + 0.61744\,(100T_{-12})$

B.1.4.2 25–35°N

400 mb $Z_0 = 621.82 + 0.97594\,(500Z_0) + 2.2969\,(500T_0)$

400 mb $T_0 = - 386.06 - 0.65129\,(500Z_0) - 0.44416\,(500T_0) + 0.65129\,(400Z_0)$

300 mb $Z_0 = 817.16 + 0.94761\,(500Z_0) + 3.0894\,(500T_0) + 0.44116\,(300Z_{-12})$
$- 0.44116\,(500Z_{-12})$

300 mb $Z_0 = 877.32 + 0.94372\,(400Z_0) + 2.9377\,(400T_0)$

300 mb $T_0 = - 272.55 - 0.19914\,(500Z_0) - 0.38498\,(500T_0) + 0.33833\,(300T_{-12})$
$+ 0.19914\,(300Z_0)$

300 mb $T_0 = - 288.62 - 0.37651\,(400Z_0) - 0.32711\,(400T_0) - 0.25106\,(300T_{-12})$
$+ 0.37651\,(300Z_0)$

250 mb $Z_0 = 596.27 + 0.96151(300Z_0) + 1.8806(300T_0)$

250 mb $T_0 = -220.45 - 0.45167(300Z_0) + 0.33843(250T_{-12}) - 0.18064(300T_{-12})$
$+ 0.45167(250Z_0)$

200 mb $Z_0 = 766.32 + 0.94682(250Z_0) + 2.1916(250T_0)$

200 mb $T_0 = -325.87 - 0.54177(250Z_0) - 0.55888(250T_0) + 0.24364(200T_{-12})$
$+ 0.54177(200Z_0)$

150 mb $Z_0 = 1091.0 + 0.90587(200Z_0) + 2.2040(200T_0)$

150 mb $T_0 = -393.31 - 0.51311(200Z_0) - 0.71958(200T_0) + 0.20260(150T_{-12})$
$+ 0.51311(150Z_0)$

100 mb $Z_0 = 1184.8 + 0.87474(150Z_0) + 1.6587(150T_0) + 0.37570(100Z_{-12})$
$- 0.37570(150Z_{-12})$

100 mb $T_0 = -149.61 - 0.14316(150Z_0) + 0.49699(100T_{-12}) + 0.14316(100Z_0)$

<u>B.1.4.3 35–45°N</u>

400 mb $Z_0 = 632.57 + 0.96932(500Z_0) + 2.2196(500T_0)$

400 mb $T_0 = -344.03 - 0.57721(500Z_0) - 0.30795(500T_0) + 0.57721(400Z_0)$

300 mb $Z_0 = 1008.2 + 0.95621(500Z_0) + 3.4029(500T_0) + 0.27219(300Z_{-12})$
$- 0.27219(500Z_{-12})$

300 mb $Z_0 = 808.53 + 0.96890(400Z_0) + 2.7007(400T_0)$

300 mb $T_0 = -355.77 - 0.26194(500Z_0) - 0.59606(500T_0) + 0.23115(300T_{-12})$
$+ 0.26194(300Z_0)$

300 mb $T_0 = -395.58 - 0.52021(400Z_0) - 0.66210(400T_0) + 0.17812(300T_{-12})$
$+ 0.52021(300Z_0)$

250 mb $Z_0 = 605.70 + 0.95904(300Z_0) + 1.9353(300T_0)$

250 mb $T_0 = 448.66 - 0.93017(300Z_0) = 0.82981(300T_0) + 0.12364(250T_{-12})$
$+ 0.93017(250Z_0)$

200 mb $Z_0 = 767.94 + 0.94484(250Z_0) + 2.0803(250T_0)$

200 mb $T_0 = -479.16 - 0.80121(250Z_0) - 0.90957(250T_0) + 0.80121(200Z_0)$

150 mb $Z_0 = 1041.6 + 0.91377(200Z_0) + 1.8716(200T_0)$

150 mb $T_0 = -285.18 - 0.446783(200Z_0) - 0.48940(200T_0) + 0.43194(150Z_0)$

100 mb $Z_0 = 656.20 + 0.82111(150Z_0) + 1.4108(150T_0) + 0.53913(100Z_{-12}) - 0.40248(150Z_{-12})$

100 mb $T_0 = -252.24 - 0.23388(150Z_0) - 0.29674(150T_0) + 0.33362(100T_{-12}) + 0.23388(100Z_0)$

B.1.4.4 45–55°N

400 mb $Z_0 = 595.32 + 0.98839(500Z_0) + 2.1288(500T_0)$

400 mb $T_0 = -256.60 - 0.42436(500Z_0) + 0.42436(400Z_0)$

300 mb $Z_0 = 1090.4 + 0.96440(500Z_0) + 3.5450(500T_0) + 0.19219(300Z_{-12}) - 0.19219(500Z_{-12})$

300 mb $Z_0 = 844.40 + 0.95304(400Z_0) + 2.6843(400T_0)$

300 mb $T_0 = -376.03 - 0.27651(500Z_0) - 0.73220(500T_0) + 0.22616(300T_{-12}) + 0.27651(300Z_0)$

300 mb $T_0 = -413.10 - 0.54190(400Z_0) - 0.73773(400T_0) + 0.15365(300T_{-12}) + 0.54190(300Z_0)$

250 mb $Z_0 = 596.22 + 0.95972(300Z_0) + 1.8002(300T_0)$

250 mb $T_0 = -507.64 - 1.0474(300Z_0) - 0.97244(300T_0) + 1.0474(250Z_0)$

200 mb $Z_0 = 768.52 + 0.94137(250Z_0) + 1.8987(250T_0)$

200 mb $T_0 = -25.041 - 0.202209(250Z_0) + 0.25833(250T_0) + 0.29553(200T_{-12}) + 0.17758(200Z_0)$

150 mb $Z_0 = 987.15 + 0.92914(200Z_0) + 2.0046(200T_0)$

150 mb $T_0 = -86.360 - 0.256806(200Z_0) + 0.22912(150Z_0)$

100 mb $Z_0 = 773.43 + 0.82019(150Z_0) + 1.5487(150T_0) + 0.43879(100Z_{-12}) - 0.30660(150Z_{-12})$

100 mb $T_0 = -346.47 - 0.32148(150Z_0) - 0.32855(150T_0) + 0.32148(100Z_0)$

B.1.4.5 55–65°N

400 mb $Z_0 = 584.54 + 0.99394(500Z_0) + 2.1315(500T_0)$

400 mb $T_0 = -362.53 - 0.61015(500Z_0) - 0.35196(500T_0) + 0.61015(400Z_0)$

300 mb $Z_0 = 1023.6 + 0.98663(500Z_0) + 3.4503(500T_0) + 0.21071(300Z_{-12}) - 0.21071(500Z_{-12})$

$$300\text{ mb} \quad Z_0 = 797.15 + 0.97012\,(400Z_0) + 2.5359\,(400T_0)$$

$$300\text{ mb} \quad T_0 = -369.11 - 0.27178\,(500Z_0) - 0.78274\,(500T_0) + 0.28637\,(300T_{-12}) + 0.27178\,(300Z_0)$$

$$300\text{ mb} \quad T_0 = -410.73 - 0.53915\,(400Z_0) - 0.77094\,(400T_0) + 0.19345\,(300T_{-12}) + 0.53915\,(300Z_0)$$

$$250\text{ mb} \quad Z_0 = 618.35 + 0.95092\,(300Z_0) + 1.7531\,(300T_0)$$

$$250\text{ mb} \quad T_0 = -496.94 - 1.0262\,(300Z_0) - 0.92485\,(300T_0) + 1.0262\,(250Z_0)$$

$$200\text{ mb} \quad Z_0 = 763.87 + 0.93930\,(250Z_0) + 1.7082\,(250T_0)$$

$$200\text{ mb} \quad T_0 = 430.17 - 0.72426\,(250Z_0) - 0.67308\,(250T_0) + 0.72426\,(200Z_0)$$

$$150\text{ mb} \quad Z_0 = 864.45 + 0.96060\,(200Z_0) + 1.9861\,(200T_0)$$

$$150\text{ mb} \quad T_0 = -346.83 - 0.45282\,(200Z_0) - 0.34739\,(200T_0) + 0.45282\,(150Z_0)$$

$$100\text{ mb} \quad Z_0 = 742.88 + 0.98276\,(150Z_0) + 2.1891\,(150T_0) + 0.35666\,(100Z_{-12}) - 0.35666\,(150Z_{-12})$$

$$100\text{ mb} \quad T_0 = -204.30 - 0.19001\,(150Z_0) + 0.22212\,(100T_{-12}) + 0.19001\,(100Z_0)$$

B.1.4.6 65–90°N

$$400\text{ mb} \quad Z_0 = 622.47 + 0.97229\,(500Z_0) + 2.1412\,(500T_0)$$

$$400\text{ mb} \quad T_0 = -346.70 - 0.58108\,(500Z_0) - 0.31663\,(500T_0) + 0.58108\,(400Z_0)$$

$$300\text{ mb} \quad Z_0 = 1079.0 + 0.92800\,(500Z_0) + 3.2584\,(500T_0) + 0.24573\,(300Z_{-12}) - 0.24573\,(500Z_{-12})$$

$$300\text{ mb} \quad Z_0 = 861.41 + 0.94166\,(400Z_0) + 2.5871\,(400T_0)$$

$$300\text{ mb} \quad T_0 = -410.43 - 0.30303\,(500Z_0) - 0.88779\,(500T_0) + 0.24852\,(300T_{-12}) + 0.30303\,(300Z_0)$$

$$300\text{ mb} \quad T_0 = -535.63 - 0.70453\,(400Z_0) - 1.0405\,(400T_0) + 0.70453\,(300Z_0)$$

$$250\text{ mb} \quad Z_0 = 632.52 + 0.94520\,(300Z_0) + 1.7471\,(300T_0)$$

$$250\text{ mb} \quad T_0 = -469.23 - 0.97097\,(300Z_0) - 0.90401\,(300T_0) + 0.10183\,(250T_{-12}) + 0.97097\,(250Z_0)$$

$$200\text{ mb} \quad Z_0 = 676.82 + 0.96655\,(250Z_0) + 1.7691\,(250T_0)$$

$$200\text{ mb} \quad T_0 = -317.69 - 0.52450\,(250Z_0) - 0.33968\,(250T_0) + 0.52450\,(200Z_0)$$

$$150\text{ mb}\quad Z_0 = 718.38 + 1.0007\,(200Z_0) + 2.0654\,(200T_0)$$

$$150\text{ mb}\quad T_0 = -\,395.51 - 0.51998\,(200Z_0) - 0.49043\,(200T_0) + 0.51998\,(150Z_0)$$

$$100\text{ mb}\quad Z_0 = 588.05 + 1.0119\,(150Z_0) + 2.3079\,(150T_0) + 0.39626\,(100Z_{-12}) - 0.39626\,(150Z_{-12})$$

$$100\text{ mb}\quad T_0 = -\,247.42 - 0.1953258\,(150Z_0) + 0.26362\,(100T_{-12}) + 0.20314\,(100Z_0)$$

B.2 Navy Equations, for 50 and 30 mb

B.2.1 January

B.2.1.1 0–19°N

$$50\text{ mb}\quad Z_0 = 2541.416 + 0.819\,(100Z_0) + 2.967\,(100T_0)$$

$$50\text{ mb}\quad T_0 = 41.201 - 0.015\,(100Z_0) + 0.291\,(100T_0)$$

$$30\text{ mb}\quad Z_0 = 677.860 + 1.082\,(50Z_0) + 2.859\,(50T_0)$$

$$30\text{ mb}\quad T_0 = -\,234.379 + 0.030\,(50Z_0) + 0.422\,(50T_0)$$

B.2.1.2 20-29°N

$$50\text{ mb}\quad Z_0 = 3533.167 + 0.619\,(100Z_0) + 1.697\,(100T_0)$$

$$50\text{ mb}\quad T_0 = 101.667 - 0.030\,(100Z_0) + 0.002\,(100T_0)$$

$$30\text{ mb}\quad Z_0 = 411.119 + 1.122\,(50Z_0) + 2.919\,(50T_0)$$

$$30\text{ mb}\quad T_0 = -\,296.825 + 0.040\,(50Z_0) + 0.418\,(50T_0)$$

B.2.1.3 30–39°N

$$50\text{ mb}\quad Z_0 = 2197.972 + 0.901\,(100Z_0) + 4.206\,(100T_0)$$

$$50\text{ mb}\quad T_0 = -\,16.853 - 0.003\,(100Z_0) + 0.421\,(100T_0)$$

$$30\text{ mb}\quad Z_0 = 1006.255 + 1.045\,(50Z_0) + 4.210\,(50T_0)$$

$$30\text{ mb}\quad T_0 = -\,111.625 + 0.015\,(50Z_0) + 0.785\,(50T_0)$$

B.2.1.4 40–49°N

$$50\text{ mb}\quad Z_0 = 1357.186 + 1.074\,(100Z_0) + 5.453\,(100T_0)$$

$$50\text{ mb}\quad T_0 = -\,161.097 + 0.027\,(100Z_0) + 0.722\,(100T_0)$$

$$30\text{ mb}\quad Z_0 = 1156.571 + 1.028\,(50Z_0) + 4.948\,(50T_0)$$

$$30\text{ mb}\quad T_0 = -\,37.062 + 0.006\,(50Z_0) + 1.060\,(50T_0)$$

B.2.1.5 50–59°N

50 mb $Z_0 = 1703.937 + 1.027\,(100Z_0) + 7.247\,(100T_0)$

50 mb $T_0 = -\ 39.900 + 0.009\,(100Z_0) + 1.182\,(100T_0)$

30 mb $Z_0 = 1373.147 + 0.997\,(50Z_0) + 5.189\,(50T_0)$

30 mb $T_0 = 24.697 - 0.003\,(50Z_0) + 1.104\,(50T_0)$

B.2.1.6 60–69°N

50 mb $Z_0 = 1849.552 + 1.001\,(100Z_0) + 7.448\,(100T_0)$

50 mb $T_0 = 25.856 - 0.003\,(100Z_0) + 1.230\,(100T_0)$

30 mb $Z_0 = 1399.180 + 0.992\,(50Z_0) + 5.040\,(50T_0)$

30 mb $T_0 = 67.613 - 0.009\,(50Z_0) + 1.142\,(50T_0)$

B.2.1.7 70–90°N

50 mb $Z_0 = 1776.246 + 1.012\,(100Z_0) + 7.208\,(100T_0)$

50 mb $T_0 = 5.698 + 0.000\,(100Z_0) + 1.169\,(100T_0)$

30 mb $Z_0 = 1761.325 + 0.943\,(50Z_0) + 5.770\,(50T_0)$

30 mb $T_0 = 177.576 - 0.024\,(50Z_0) + 1.326\,(50T_0)$

B.2.2 April

B.2.2.1 0–19°N

50 mb $Z_0 = 2884.129 + 0.761\,(100Z_0) + 3.233\,(100T_0)$

50 mb $T_0 = 213.412 - 0.046\,(100Z_0) + 0.372\,(100T_0)$

30 mb $Z_0 = 514.297 + 1.103\,(50Z_0) + 2.495\,(50T_0)$

30 mb $T_0 = -\ 223.826 + 0.027\,(50Z_0) + 0.253\,(50T_0)$

B.2.2.2 20–29°N

50 mb $Z_0 = 2757.580 + 0.785\,(100Z_0) + 3.214\,(100T_0)$

50 mb $T_0 = 63.839 - 0.021\,(100Z_0) + 0.136\,(100T_0)$

30 mb $Z_0 = 409.690 + 1.124\,(50Z_0) + 3.069\,(50T_0)$

30 mb $T_0 = -\ 271.813 + 0.037\,(50Z_0) + 0.473\,(50T_0)$

B.2.2.3 30–39°N

$$50\text{ mb}\quad Z_0 = 2253.952 + 0.891\,(100Z_0) + 4.094\,(100T_0)$$
$$50\text{ mb}\quad T_0 = 13.654 - 0.009\,(100Z_0) + 0.355\,(100T_0)$$
$$30\text{ mb}\quad Z_0 = 768.846 + 1.079\,(50Z_0) + 4.040\,(50T_0)$$
$$30\text{ mb}\quad T_0 = -\ 217.029 + 0.030\,(50Z_0) + 0.728\,(50T_0)$$

B.2.2.4 40–49°N

$$50\text{ mb}\quad Z_0 = 1992.518 + 0.940\,(100Z_0) + 3.999\,(100T_0)$$
$$50\text{ mb}\quad T_0 = -\ 14.231 - 0.003\,(100Z_0) + 0.429\,(100T_0)$$
$$30\text{ mb}\quad Z_0 = 999.604 + 1.046\,(50Z_0) + 4.255\,(50T_0)$$
$$30\text{ mb}\quad T_0 = -\ 111.154 + 0.015\,(50Z_0) + 0.814\,(50T_0)$$

B.2.2.5 50–59°N

$$50\text{ mb}\quad Z_0 = 1738.520 + 0.999\,(100Z_0) + 4.978\,(100T_0)$$
$$50\text{ mb}\quad T_0 = -\ 35.693 + 0.033\,(100Z_0) + 0.622\,(100T_0)$$
$$30\text{ mb}\quad Z_0 = 1093.054 + 1.032\,(50Z_0) + 4.280\,(50T_0)$$
$$30\text{ mb}\quad T_0 = -\ 91.110 + 0.012\,(50Z_0) + 0.828\,(50T_0)$$

B.2.2.6 60–69°N

$$50\text{ mb}\quad Z_0 = 1565.265 + 1.045\,(100Z_0) + 6.320\,(100T_0)$$
$$50\text{ mb}\quad T_0 = -\ 69.546 + 0.012\,(100Z_0) + 0.903\,(100T_0)$$
$$30\text{ mb}\quad Z_0 = 1011.577 + 1.047\,(50Z_0) + 4.681\,(50T_0)$$
$$30\text{ mb}\quad T_0 = -\ 128.145 + 0.018\,(50Z_0) + 0.915\,(50T_0)$$

B.2.2.7 70–90°N

$$50\text{ mb}\quad Z_0 = 1521.312 + 1.060\,(100Z_0) + 7.084\,(100T_0)$$
$$50\text{ mb}\quad T_0 = -\ 73.812 + 0.015\,(100Z_0) + 1.160\,(100T_0)$$
$$30\text{ mb}\quad Z_0 = 1151.790 + 1.028\,(50Z_0) + 4.947\,(50T_0)$$
$$30\text{ mb}\quad T_0 + -\ 60.790 + 0.009\,(50Z_0) + 1.040\,(50T_0)$$

B.2.3 July

B.2.3.1 0–19°N

$$50\text{ mb}\quad Z_0 = 1329.789 + 1.038\,(100Z_0) + 2.268\,(100T_0)$$

50 mb $T_0 = -130.070 + 0.015\,(100Z_0) + 0.187\,(100T_0)$

30 mb $Z_0 = 1353.682 + 0.979\,(50Z_0) + 2.446\,(50T_0)$

30 mb $T_0 = -245.159 + 0.030\,(50Z_0) + 0.261\,(50T_0)$

B.2.3.2 20–29°N

50 mb $Z_0 = 1888.503 + 0.944\,(100Z_0) + 2.796\,(100T_0)$

50 mb $T_0 = -79.342 + 0.006\,(100Z_0) + 0.181\,(100T_0)$

30 mb $Z_0 = 907.650 + 1.047\,(50Z_0) + 2.703\,(50T_0)$

30 mb $T_0 = -111.434 + 0.012\,(50Z_0) + 0.401\,(50T_0)$

B.2.3.3 30-39°N

50 mb $Z_0 = 1688.097 + 0.993\,(100Z_0) + 3.597\,(100T_0)$

50 mb $T_0 = -87.255 + 0.009\,(100Z_0) + 0.281\,(100T_0)$

30 mb $Z_0 = 798.473 + 1.069\,(50Z_0) + 3.406\,(50T_0)$

30 mb $T_0 = -147.468 + 0.018\,(50Z_0) + 0.499\,(50T_0)$

B.2.3.4 40–49°N

50 mb $Z_0 = 1948.918 + 0.947\,(100Z_0) + 3.613\,(100T_0)$

50 mb $T_0 = -49.948 + 0.003\,(100Z_0) + 0.324\,(100T_0)$

30 mb $Z_0 = 875.143 + 1.058\,(50Z_0) + 3.421\,(50T_0)$

30 mb $T_0 = -167.540 + 0.021\,(50Z_0) + 0.516\,(50T_0)$

B.2.3.5 50–59°N

50 mb $Z_0 = 1550.912 + 1.037\,(100Z_0) + 5.176\,(100T_0)$

50 mb $T_0 = -101.673 + 0.015\,(100Z_0) + 0.575\,(100T_0)$

30 mb $Z_0 = 781.138 + 1.073\,(50Z_0) + 3.607\,(50T_0)$

30 mb $T_0 = -182.025 + 0.024\,(50Z_0) + 0.657\,(50T_0)$

B.2.3.6 60–69°N

50 mb $Z_0 = 1454.129 + 1.060\,(100Z_0) + 5.664\,(100T_0)$

50 mb $T_0 = -108.563 + 0.018\,(100Z_0) + 0.756\,(100T_0)$

30 mb $Z_0 = 1040.348 + 1.042\,(50Z_0) + 4.590\,(50T_0)$

30 mb $T_0 = -84.710 + 0.012\,(50Z_0) + 0.950\,(50T_0)$

B.2.3.7 70–90°N

50 mb $Z_0 = 1691.480 + 1.011\,(100Z_0) + 4.947\,(100T_0)$

50 mb $T_0 = -\ 17.860 + 0.000\,(100Z_0) + 0.551\,(100T_0)$

30 mb $Z_0 = 1109.365 + 1.026\,(50Z_0) + 3.622\,(50T_0)$

30 mb $T_0 = -\ 35.241 + 0.003\,(50Z_0) + 0.633\,(50T_0)$

B.2.4 October

B.2.4.1 0–19°N

50 mb $Z_0 = 2471.473 + 0.845\,(100Z_0) + 3.594\,(100T_0)$

50 mb $T_0 = -\ 4.789 - 0.006\,(100Z_0) + 0.315\,(100T_0)$

30 mb $Z_0 = 414.772 + 1.119\,(50_Z) + 2.678\,(50T_0)$

30 mb $T_0 = -\ 256.894 + 0.034\,(50Z_0) + 0.402\,(50T_0)$

B.2.4.2 20–29°N

50 mb $Z_0 = 2172.734 + 0.895\,(100Z_0) + 3.155\,(100T_0)$

50 mb $T_0 = -\ 28.805 - 0.003\,(100Z_0) + 0.205\,(100T_0)$

30 mb $Z_0 = 840.373 + 1.056\,(50Z_0) + 2.621\,(50T_0)$

30 mb $T_0 = -\ 134.085 + 0.015\,(50Z_0) + 0.375\,(50T_0)$

B.2.4.3 30–39°N

50 mb $Z_0 = 1908.796 + 0.949\,(100Z_0) + 3.501\,(100T_0)$

50 mb $T_0 = -\ 74.893 + 0.006\,(100Z_0) + 0.251\,(100T_0)$

30 mb $Z_0 = 974.336 + 1.044\,(50Z_0) + 3.530\,(50T_0)$

30 mb $T_0 = -\ 103.101 + 0.012\,(50Z_0) + 0.565\,(50T_0)$

B.2.4.4 40–49°N

50 mb $Z_0 = 1564.083 + 1.024\,(100Z_0) + 4.398\,(100T_0)$

50 mb $T_0 = -\ 111.220 + 0.015\,(100Z_0) + 0.461\,(100T_0)$

30 mb $Z_0 = 861.734 + 1.064\,(50Z_0) + 4.006\,(50T_0)$

30 mb $T_0 = -\ 158.949 + 0.021\,(50Z_0) + 0.704\,(50T_0)$

B.2.4.5 50–59°N

$$50\text{ mb}\quad Z_0 = 1674.144 + 1.016\,(100Z_0) + 5.560\,(100T_0)$$

$$50\text{ mb}\quad T_0 = -61.565 + 0.009\,(100Z_0) + 0.772\,(100T_0)$$

$$30\text{ mb}\quad Z_0 = 1091.373 + 1.034\,(50Z_0) + 4.555\,(50T_0)$$

$$30\text{ mb}\quad T_0 = -88.217 + 0.012\,(50Z_0) + 0.898\,(50T_0)$$

B.2.4.6 60–69°N

$$50\text{ mb}\quad Z_0 = 1535.147 + 1.050\,(100Z_0) + 6.341\,(100T_0)$$

$$50\text{ mb}\quad T_0 = -67.682 + 0.012\,(100Z_0) + 0.971\,(100T_0)$$

$$30\text{ mb}\quad Z_0 = 1233.344 + 1.017\,(50Z_0) + 5.103\,(50T_0)$$

$$30\text{ mb}\quad T_0 = -38.939 + 0.006\,(50Z_0) + 1.067\,(50T_0)$$

B.2.4.7 70–90°N

$$50\text{ mb}\quad Z_0 = 1461.713 + 1.060\,(100Z_0) + 6.030\,(100T_0)$$

$$50\text{ mb}\quad T_0 = -88.606 + 0.015\,(100Z_0) + 0.901\,(100T_0)$$

$$30\text{ mb}\quad Z_0 = 1319.242 + 1.005\,(50Z_0) + 5.232\,(50T_0)$$

$$30\text{ mb}\quad T_0 = 27.912 - 0.003\,(50Z_0) + 1.181\,(50T_0)$$

APPENDIX C

RESULTS OBTAINED FROM VERTICAL-EXTRAPOLATION EQUATIONS, FOR DEPENDENT AND INDEPENDENT DATA

January, 0–25°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jan. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Dec. r.m.s.e.‡	Feb. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	695	32.6 ft	22.7 ft	150.9 ft	194.2 ft	16.2 ft	30.8 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$, $400T_{-12}$	695	0.94°C	0.9°C	2.44°C	2.1°C	0.6°C	1.2°C
$300Z_0$	$500T_0$, $500Z_0$, $500\text{-}300H_{-12}$, $300Z_{-12}$	695	57.8 ft	42.1 ft	191.8 ft	231.6 ft	27.9 ft	47.6 ft
$300Z_0$	$400Z_0$, $400T_0$	695	46.9 ft	31.3 ft	191.8 ft	231.6 ft	23.1 ft	30.0 ft
$300T_0$	$300T_{-12}$, $500\text{-}300H_0$, $500\text{-}300T_{m,-12}$	695	1.17°C	1.0°C	2.80°C	2.3°C	0.7°C	1.1°C
$300T_0$	$400\text{-}300H_0$, $300T_{-12}$, $400\text{-}300T_{m,-12}$	695	1.08°C	0.8°C	2.80°C	2.3°C	0.7°C	0.9°C
$250Z_0$	$300Z_0$, $300T_0$	682	41.6 ft	18.0 ft	221.2 ft	257.9 ft	9.1 ft	24.3 ft
$250T_0$	$300\text{-}250H_0$, $250T_{-12}$, $300\text{-}250T_{m,-12}$, $300Z_0$	682	1.07°C	0.67°C	2.77°C	2.0°C	0.6°C	1.1°C
$200Z_0$	$250Z_0$, $250T_0$	682	41.1 ft	17.0 ft	253.8 ft	286.7 ft	16.2 ft	25.6 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	682	0.82°C	0.68°C	2.42°C	2.1°C	0.9°C	1.4°C
$150Z_0$	$200Z_0$, $200T_0$	653	41.5 ft	35.5 ft	257.4 ft	298.6 ft	26.6 ft	35.1 ft
$150T_0$	$150T_{-12}$, $200\text{-}150H_0$, $200T_0$	653	0.99°C	1.05°C	1.86°C	1.8°C	1.3°C	1.1°C
$100Z_0$	$150Z_0$, $150\text{-}100H_{-12}$, $150T_0$	653	67.0 ft	48.4 ft	199.7 ft	228.5 ft	60.5 ft	50.5 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$	653	1.29°C	1.43°C	3.10°C	4.0°C	2.1°C	1.1°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

January, 25–35°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jan. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Dec. r.m.s.e.‡	Feb. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	866	34.2 ft	20.9 ft	359.1 ft	334.0 ft	22.8 ft	34.5 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	866	1.05°C	1.0°C	3.79°C	4.8°C	1.2°C	1.3°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	866	71.6 ft	59.2 ft	428.1 ft	427.8 ft	51.5 ft	90.9 ft
$300Z_0$	$400Z_0$, $400T_0$	866	47.6 ft	36.1 ft	428.1 ft	427.8 ft	39.9 ft	54.4 ft
$300T_0$	$500\text{-}300H_0$, $500T_0$, $300T_{-12}$	866	1.47°C	1.2°C	3.72°C	4.4°C	1.1°C	2.5°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	866	1.19°C	0.9°C	3.72°C	4.4°C	0.9°C	1.6°C
$250Z_0$	$300Z_0$, $300T_0$	842	38.2 ft	19.7 ft	452.2 ft	472.8 ft	14.3 ft	24.2 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$, $250T_{-12}$	842	1.10°C	0.9°C	4.01°C	2.8°C	0.6°C	1.2°C
$200Z_0$	$250Z_0$, $250T_0$	842	59.5 ft	35.7 ft	471.2 ft	485.8 ft	19.4 ft	42.0 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$, $200T_{-12}$	842	1.76°C	1.6°C	4.93°	2.5°C	0.9°C	1.5°C
$150Z_0$	$200Z_0$, $200T_0$, $200\text{-}150H_{-12}$	745	66.5 ft	46.2 ft	449.5 ft	426.8 ft	29.3 ft	41.0 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $200Z_0$	745	1.51°C	2.0°C	3.76°C	4.1°C	1.5°C	1.6°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	745	66.6 ft	61.1 ft	348.6 ft	259.5 ft	59.5 ft	59.1 ft
$100T_0$	$150Z_0$, $150\text{-}100H_0$, $150T_0$, $100T_{-12}$	745	1.50°C	1.3°C	4.40°C	4.8°C	1.5°C	1.7°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

January, 35–45°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jan. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Dec. r.m.s.e.‡	Feb. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	1082	38.7 ft	25.4 ft	581.9 ft	628.0 ft	17.5 ft	18.9 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	1082	1.13°C	1.3°C	5.32°C	4.9°C	0.9°C	0.9°C
$500Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	1082	86.1 ft	71.7 ft	674.1 ft	748.6 ft	66.4 ft	65.8 ft
$300Z_0$	$400Z_0$, $400T_0$, $400\text{-}300H_{-12}$	1082	44.3 ft	36.9 ft	674.1 ft	748.6 ft	24.7 ft	29.3 ft
$300T_0$	$500\text{-}300H_0$, $500T_0$, $300T_{-12}$	1082	1.67°C	1.9°C	3.94°C	5.4°C	0.7°C	1.7°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	1082	1.11°C	1.2°C	3.94°C	5.4°C	0.7°C	1.1°C
$250Z_0$	$300Z_0$, $300T_0$	1087	42.9 ft	25.7 ft	692.2 ft	774.6 ft	29.2 ft	22.1 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	1087	1.09°C	1.2°C	4.07°C	3.3°C	0.9°C	0.8°C
$200Z_0$	$250Z_0$, $250T_0$, $250\text{-}200H_{-12}$	1087	64.1 ft	36.5 ft	649.7 ft	607.3 ft	26.6 ft	37.8 ft
$200T_0$	$250\text{-}200H_0$, $200T_{-12}$, $250T_0$, $250Z_0$	1087	2.46°C	1.6°C	6.05°C	5.7°C	1.3°C	2.2°C
$150Z_0$	$200Z_0$, $200T_0$, $200\text{-}150H_{-12}$, $150Z_{-12}$	981	69.3 ft	50.7 ft	571.4 ft	630.1 ft	43.4 ft	33.0 ft
$150T_0$	$200\text{-}150H_0$, $200Z_0$, $200T_0$, $150T_{-12}$	981	1.82°C	1.3°C	5.00°C	4.8°C	1.4°C	1.1°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$, $100Z_{-12}$	981	72.1 ft	57.3 ft	459.0 ft	509.2 ft	46.1 ft	46.3 ft
$100T_0$	$150\text{-}100H_0$, $150T_0$, $100T_{-12}$	981	1.56°C	1.7°C	4.63°C	4.8°C	1.2°C	1.5°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

January, 45–55°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jan. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Dec. r.m.s.e.‡	Feb. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	834	37.3 ft	19.9 ft	735.1 ft	726.3 ft	20.5 ft	20.1 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	834	1.15°C	0.8°C	6.02°C	6.0°C	0.5°C	1.0°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	834	93.9 ft	71.7 ft	834.1 ft	831.2 ft	50.3 ft	65.4 ft
$300Z_0$	$400Z_0$, $400T_0$, $400\text{-}300H_{-12}$	834	52.3 ft	36.0 ft	834.1 ft	831.2 ft	37.9 ft	32.7 ft
$300T_0$	$300T_{-12}$, $500\text{-}300H_0$, $500T_0$	834	1.87°C	1.6°C	4.19°C	3.2°C	2.3°C	1.1°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	834	1.24°C	1.8°C	4.19°C	3.2°C	1.1°C	0.9°C
$250Z_0$	$300Z_0$, $300\text{-}250H_{-12}$	833	62.6 ft	39.6 ft	1405.5 ft	820.9 ft	66.5 ft	43.4 ft
$250T_0$	$250T_{-12}$, $300T_0$, $300Z_0$, $300\text{-}250H_0$	833	2.11°C	1.9°C	5.14°C	4.4°C	1.9°C	2.0°C
$200Z_0$	$250Z_0$, $250\text{-}200H_{-12}$, $200Z_{-12}$, $250T_0$	833	68.6 ft	52.4 ft	1504.5 ft	729.6 ft	61.8 ft	46.1 ft
$200T_0$	$200T_{-12}$, $250T_0$, $250\text{-}200H_0$, $250Z_0$	833	2.76°C	3.0°C	6.88°C	6.8°C	2.5°C	2.7°C
$150Z_0$	$200Z_0$, $200T_0$, $200\text{-}150H_{-12}$, $150Z_{-12}$	774	59.7 ft	49.7 ft	689.2 ft	622.9 ft	46.5 ft	34.7 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $150T_{-12}$	774	1.30°C	1.4°C	5.44°C	5.1°C	1.6°C	1.4°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	774	65.2 ft	41.4 ft	661.8 ft	523.2 ft	49.5 ft	43.9 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$, $150T_0$	774	1.46°C	1.4°C	4.70°C	4.8°C	1.0°C	1.6°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

January, 55–65°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jan. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Dec. r.m.s.e.‡	Feb. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	818	38.1 ft	24.1 ft	649.9 ft	676.5 ft	28.0 ft	30.6 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	818	1.29°C	0.9°C	4.99°C	4.6°C	0.7°C	1.2°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	818	84.8 ft	70.1 ft	718.9 ft	766.7 ft	93.4 ft	123.6 ft
$300Z_0$	$400Z_0$, $400T_0$, $400\text{-}300H_{-12}$	818	49.1 ft	38.2 ft	718.9 ft	766.7 ft	40.2 ft	51.6 ft
$300T_0$	$300T_{-12}$, $500\text{-}300H_0$, $500T_0$	818	1.91°C	1.9°C	3.86°C	3.5°C	2.0°C	1.8°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	818	1.21°C	1.3°C	3.86°C	3.5°C	1.4°C	1.5°C
$250Z_0$	$300Z_0$, $300T_0$, $300\text{-}250H_{-12}$	812	41.9 ft	24.9 ft	708.1 ft	767.6 ft	32.3 ft	27.5 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	812	1.22°C	1.1°C	5.55°C	4.4°C	1.3°C	1.6°C
$200Z_0$	$250Z_0$, $250T_0$, $250\text{-}200H_{-12}$, $200Z_{-12}$	812	49.0 ft	34.8 ft	587.9 ft	735.1 ft	33.0 ft	31.7 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$, $200T_{-12}$	812	1.41°C	1.9°C	6.59°C	5.5°C	1.1°C	1.9°C
$150Z_0$	$200Z_0$, $200T_0$, $200\text{-}150H_{-12}$, $150Z_{-12}$	713	53.7 ft	40.7 ft	702.1 ft	713.5 ft	34.0 ft	35.9 ft
$150T_0$	$200\text{-}150H_0$, $150T_{-12}$, $200\text{-}150T_{m,-12}$	713	1.18°C	1.3°C	6.30°C	5.5°C	1.7°C	0.9°C
$100Z_0$	$100Z_{-12}$, $150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	713	66.8 ft	47.6 ft	853.4 ft	764.9 ft	38.8 ft	54.6 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$	713	1.39°C	1.3°C	6.90°C	6.2°C	1.4°C	1.2°C

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† Fifty independent cases for each predictand.

‡ Twenty-five cases for each predictand.

January, 65–90°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jan. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Dec. r.m.s.e.‡	Feb. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	865	34.1 ft	21.8 ft	525.9 ft	681.3 ft	24.5 ft	18.6 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	865	1.01°C	0.8°C	4.60°C	8.9°C	0.6°C	0.8°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	865	73.6 ft	95.6 ft	594.9 ft	898.1 ft	63.8 ft	78.5 ft
$300Z_0$	$400Z_0$, $400T_0$, $400\text{-}300H_{-12}$	865	46.1 ft	50.4 ft	594.9 ft	898.1 ft	36.1 ft	45.1 ft
$300T_0$	$300T_{-12}$, $500\text{-}300H_0$, $500T_0$	865	1.57°C	1.4°C	3.67°C	4.6°C	1.5°C	1.5°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	865	1.00°C	1.4°C	3.67°C	4.6°C	0.9°C	1.1°C
$250Z_0$	$300Z_0$, $300T_0$, $300\text{-}250H_{-12}$	852	38.7 ft	30.7 ft	610.8 ft	894.0 ft	24.9 ft	17.0 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	852	1.06°C	1.8°C	5.11°C	6.5°C	0.9°C	0.6°C
$200Z_0$	$250Z_0$, $250T_0$, $250\text{-}200H_{-12}$	852	50.7 ft	35.0 ft	631.1 ft	877.0 ft	32.8 ft	32.8 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$, $200T_{-12}$	852	1.13°C	1.3°C	6.74°C	6.4°C	0.9°C	0.7°C
$150Z_0$	$200Z_0$, $200T_0$, $200\text{-}150H_{-12}$	764	55.8 ft	34.3 ft	720.6 ft	903.1 ft	29.4 ft	28.7 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $200Z_0$	764	0.93°C	1.3°C	6.98°C	7.5°C	0.9°C	1.2°C
$100Z_0$	$100Z_{-12}$, $150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	764	51.6 ft	42.8 ft	954.2 ft	1059.3 ft	42.0 ft	53.3 ft
$100T_0$	$150\text{-}100H_0$, $150T_0$	764	1.06°C	0.8°C	8.09°C	8.5°C	0.9°C	1.6°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

April, 0–25°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Apr. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Mar. r.m.s.e.‡	May r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	706	29.3 ft	18.1 ft	107.5 ft	112.6 ft	20.3 ft	20.6 ft
$400T_0$	$500\text{-}400H_0$, $400T_{-12}$, $500T_0$	706	0.74°C	0.6°C	2.21°C	2.0°C	0.8°C	0.7°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	706	51.0 ft	33.1 ft	153.4 ft	157.4 ft	51.8 ft	43.9 ft
$300Z_0$	$400Z_0$, $400T_0$	706	43.1 ft	22.7 ft	153.4 ft	157.4 ft	36.4 ft	25.1 ft
$300T_0$	$500\text{-}300H_0$, $300T_{-12}$, $500\text{-}300T_{m,-12}$	706	0.94°C	0.7°C	2.18°C	2.2°C	1.0°C	0.9°C
$300T_0$	$400\text{-}300H_0$, $300T_{-12}$	706	0.89°C	0.6°C	2.18°C	2.2°C	0.9°C	0.8°C
$250Z_0$	$300Z_0$, $300T_0$	694	37.5 ft	19.2 ft	177.2 ft	189.6 ft	20.7 ft	16.3 ft
$250T_0$	$300T_0$, $300\text{-}250H_0$, $250T_{-12}$	694	0.84°C	0.6°C	1.96°C	2.5°C	0.8°C	0.7°C
$200Z_0$	$250Z_0$, $250T_0$	694	34.1 ft	17.7 ft	201.3 ft	223.6 ft	16.4 ft	17.0 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	694	0.66°C	0.9°C	1.81°C	2.2°C	0.8°C	0.5°C
$150Z_0$	$200Z_0$, $200T_0$	646	46.7 ft	22.1 ft	215.6 ft	241.7 ft	21.7 ft	27.7 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$	646	0.92°C	0.9°C	1.91°C	1.4°C	0.8°C	0.6°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	646	73.1 ft	45.9 ft	177.8 ft	183.0 ft	48.8 ft	69.8 ft
$100T_0$	$100T_{-12}$, $150\text{-}100H_0$, $150Z_0$	646	1.54°C	1.2°C	3.02°C	3.6°C	1.9°C	1.9°C

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†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

April, 25–35°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Apr. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Mar. r.m.s.e.‡	May r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	824	32.0 ft	24.1 ft	288.4 ft	302.2 ft	22.0 ft	19.9 ft
$400T_0$	$500\text{-}400H_0$, $400T_{-12}$	824	0.99°C	1.1°C	3.46°C	3.7°C	0.7°C	0.9°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	824	60.5 ft	61.1 ft	365.3 ft	357.6 ft	60.7 ft	60.7 ft
$300Z_0$	$400Z_0$, $400T_0$	824	42.7 ft	27.4 ft	365.3 ft	357.6 ft	24.6 ft	35.3 ft
$300T_0$	$500\text{-}300H_0$, $500T_0$, $300T_{-12}$	824	1.16°C	1.1°C	3.33°C	3.5°C	1.2°C	1.3°C
$300T_0$	$400\text{-}300H_0$, $400T_0$	824	0.94°C	0.9°C	3.33°C	3.5°C	0.8°C	0.9°C
$250Z_0$	$300Z_0$, $300T_0$	834	31.8 ft	16.1 ft	409.2 ft	423.8 ft	22.3 ft	22.2 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	834	0.84°C	0.7°C	3.10°C	3.3°C	1.4°C	0.7°C
$200Z_0$	$250Z_0$, $250T_0$	834	49.2 ft	33.4 ft	430.9 ft	451.7 ft	30.2 ft	29.7 ft
200T	$250\text{-}200H_0$, $250T_0$	834	1.24°C	1.3°C	3.76°C	4.3°C	1.3°C	1.0°C
$150Z_0$	$200Z_0$, $200T_0$, $200\text{-}150H_{-12}$	784	59.7 ft	44.1 ft	402.1 ft	423.6 ft	36.7 ft	35.4 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $200Z_0$, $150T_{-12}$	784	1.36°C	1.7°C	3.96°C	3.9°C	1.5°C	1.7°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$, $100Z_{-12}$	784	69.8 ft	74.8 ft	305.5 ft	331.9 ft	60.2 ft	96.6 ft
$100T_0$	$100T_{-12}$, $150\text{-}100H_0$, $150T_0$	784	1.66°C	1.6°C	4.02°C	4.3°C	1.6°C	2.0°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

† Fifty independent cases for each predictand.

‡ Twenty-five cases for each predictand.

April, 35—45°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e. Dep.	R.m.s.e. Ind.†	Std. dev. Dep.	Std. dev. Ind.†	Ind. data with Apr. eqs. Mar. r.m.s.e.‡	Ind. data with Apr. eqs. May r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	1053	35.4 ft	13.6 ft	404.1 ft	455.2 ft	28.5 ft	26.4 ft
$400T_0$	$500\text{-}400H_0$, $400T_{-12}$	1053	1.06°C	0.9°C	4.38°C	4.2°C	1.4°C	0.6°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	1053	65.7 ft	46.9 ft	486.2 ft	542.9 ft	65.3 ft	59.2 ft
$300Z_0$	$400Z_0$, $400T_0$	1053	45.1 ft	32.1 ft	486.2 ft	542.9 ft	31.8 ft	30.0 ft
$300T_0$	$500\text{-}300H_0$, $500T_0$, $300T_{-12}$	1053	1.18°C	1.3°C	3.37°C	3.8°C	1.5°C	1.0°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	1053	1.06°C	1.0°C	3.37°C	3.8°C	1.2°C	0.6°C
$250Z_0$	$300Z_0$, $300T_0$	1076	40.8 ft	16.9 ft	497.5 ft	592.7 ft	20.7 ft	13.9 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	1076	0.84°C	1.0°C	3.24°C	3.5°C	1.6°C	0.8°C
$200Z_0$	$250Z_0$, $250T_0$	1076	52.4 ft	32.7 ft	465.2 ft	520.7 ft	56.8 ft	35.3 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	1076	1.40°C	1.7°C	5.26°C	5.9°C	2.1°C	1.0°C
$150Z_0$	$200Z_0$, $200T_0$, $200\text{-}150H_{-12}$	990	58.9 ft	49.2 ft	368.5 ft	442.6 ft	56.4 ft	43.6 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $200Z_0$	990	1.38°C	1.6°C	4.53°C	4.2°C	1.1°C	2.2°C
$100Z_0$	$150Z_0$, $150T_0$, $100Z_{-12}$, $150\text{-}100H_{-12}$	990	71.9 ft	66.5 ft	276.8 ft	345.3 ft	59.6 ft	59.0 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$, $150T_0$	990	1.59°C	1.4°C	3.75°C	4.0°C	1.9°C	1.7°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

April, 45–55°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Apr. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Mar. r.m.s.e.‡	May r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	788	36.6 ft	26.8 ft	510.1 ft	550.9 ft	26.9 ft	23.2 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	788	1.14°C	1.0°C	5.03°C	4.6°C	1.0°C	0.9°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	788	79.1 ft	78.8 ft	584.9 ft	715.3 ft	96.5 ft	89.2 ft
$300Z_0$	$400Z_0$, $400T_0$	788	52.4 ft	42.9 ft	584.9 ft	715.3 ft	55.8 ft	43.1 ft
$300T_0$	$300T_{-12}$, $500\text{-}300H_0$, $500T_0$	788	1.73°C	2.1°C	3.38°C	4.0°C	1.5°C	1.4°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	788	1.26°C	1.3°C	3.38°C	4.0°C	1.8°C	1.2°C
$250Z_0$	$300Z_0$, $300T_0$	806	38.5 ft	27.2 ft	569.2 ft	585.7 ft	31.5 ft	31.9 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	806	1.22°C	1.1°C	5.10°C	5.0°C	1.8°C	1.1°C
$200Z_0$	$250Z_0$, $250T_0$	806	53.9 ft	34.2 ft	479.6 ft	498.6 ft	67.9 ft	54.3 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	806	1.44°C	1.5°C	6.54°C	6.4°C	1.1°C	1.8°C
$150Z_0$	$200Z_0$, $200T_0$	753	54.4 ft	38.1 ft	384.0 ft	449.7 ft	60.0 ft	73.7 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $150T_{-12}$	753	1.14°C	1.3°C	4.34°C	4.5°C	1.1°C	1.7°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$, $100Z_{-12}$	753	60.9 ft	51.5 ft	297.3 ft	304.5 ft	66.9 ft	64.5 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$, $150\text{-}100T_{m,-12}$	753	1.29°C	1.4°C	3.32°C	3.9°C	1.5°C	1.4°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

April, 55–65°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Apr. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Mar. r.m.s.e.‡	May r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	796	38.1 ft	21.7 ft	499.3 ft	640.5 ft	24.6 ft	16.4 ft
$400T_0$	$500\text{-}400H_0$	796	1.30°C	1.1°C	4.82°C	5.26°C	0.9°C	1.0°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	796	84.1 ft	67.9 ft	568.7 ft	605.1 ft	66.3 ft	57.1 ft
$300Z_0$	$400Z_0$, $400T_0$, $400\text{-}300H_{-12}$	796	49.4 ft	34.1 ft	568.7 ft	605.1 ft	29.6 ft	30.5 ft
$300T_0$	$300T_{-12}$, $500\text{-}300H_0$, $500T_0$	796	2.02°C	1.7°C	3.89°C	3.86°C	1.5°C	2.1°C
$300T_0$	$400\text{-}300H_0$, $500T_0$, $300T_{-12}$	796	1.23°C	1.2°C	3.89°C	3.86°C	1.2°C	1.0°C
$250Z_0$	$300Z_0$, $300T_0$	788	43.3 ft	30.8 ft	532.3 ft	691.5 ft	34.8 ft	37.0 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	788	1.36°C	1.3°C	5.01°C	5.62°C	2.1°C	1.2°C
$200Z_0$	$250Z_0$, $250T_0$	788	52.8 ft	34.8 ft	471.9 ft	604.0 ft	64.6 ft	43.8 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	788	1.21°C	1.3°C	4.77°C	5.69°C	1.3°C	1.5°C
$150Z_0$	$200Z_0$, $200T_0$	762	52.8 ft	35.8 ft	425.2 ft	496.9 ft	25.3 ft	38.6 ft
$150T_0$	$200\text{-}150H_0$, $150T_{-12}$, $200\text{-}150T_{m,-12}$	762	1.08°C	1.0°C	3.44°C	4.83°C	1.1°C	1.0°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	762	72.0 ft	66.6 ft	367.3 ft	393.7 ft	52.5 ft	72.1 ft
$100T_0$	$100T_{-12}$, $150\text{-}100H_0$, $150Z_0$	762	1.29°C	1.8°C	2.76°C	4.30°C	1.3°C	1.4°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

April, 65–90°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Apr. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Mar. r.m.s.e.‡	May r.m.s.e.‡
$400Z_0$	$500Z_C$, $500T_0$	823	33.5 ft	24.6 ft	520.3 ft	624.3 ft	22.6 ft	30.4 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	823	0.96°C	1.0°C	4.29°C	4.4°C	0.8°C	0.7°C
$300Z_0$	$500Z_0$, $500\text{-}300H_{-12}$, $500T_0$	823	84.1 ft	71.3 ft	558.4 ft	640.9 ft	72.2 ft	95.2 ft
$300Z_0$	$400Z_C$, $400T_0$, $400\text{-}300H_{-12}$	823	52.8 ft	43.3 ft	558.4 ft	640.9 ft	57.7 ft	30.1 ft
$300T_0$	$300T_{-12}$, $500Z_0$, $500\text{-}300H_0$, $500T_0$	823	1.81°C	1.9°C	4.00°C	4.2°C	2.0°C	2.0°C
$300T_0$	$300T_{-12}$, $400\text{-}300H_0$, $400T_0$	823	1.30°C	1.2°C	4.00°C	4.2°C	1.7°C	1.6°C
$250Z_0$	$300Z_0$, $300T_0$	806	45.4 ft	30.1 ft	532.9 ft	600.4 ft	24.0 ft	35.6 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	806	1.13°C	1.0°C	4.87°C	5.9°C	1.0°C	1.9°C
$200Z_0$	$250Z_0$, $250T_0$	806	43.9 ft	31.0 ft	483.9 ft	520.5 ft	27.2 ft	36.4 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	806	0.89°C	1.1°C	4.13°C	5.2°C	0.9°C	1.0°C
$150Z_0$	$200Z_0$, $200T_0$	765	46.7 ft	31.6 ft	441.1 ft	416.6 ft	31.5 ft	29.0 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $150T_{-12}$	765	0.73°C	0.8°C	3.27°C	4.4°C	0.7°C	0.6°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	765	55.8 ft	46.1 ft	383.4 ft	381.1 ft	47.4 ft	82.2 ft
$100T_0$	$100T_{-12}$, $150\text{-}100H_0$, $150Z_0$	765	1.01°C	1.0°C	3.09°C	4.9°C	1.9°C	1.3°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

July, 0–25°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jul. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Jun. r.m.s.e.‡	Aug. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	727	27.0 ft		70.4 ft			
$400T_0$	$500\text{-}400H_0$, $400T_{-12}$, $500T_0$	727	0.64°C		1.51°C			
$300Z_0$	$500T_0$, $500Z_0$, $500\text{-}300H_0$, $300T_{-12}$	727	42.0 ft	43.1 ft	79.3 ft	61.5 ft	40.0 ft	48.2 ft
$300Z_0$	$400Z_0$, $400T_0$	727	37.0 ft		79.3 ft			
$300T_0$	$500\text{-}300H_0$, $300T_{-12}$, $500\text{-}300T_{m,-12}$	727	0.73°C	0.8°C	1.71°C	1.9°C	0.6°C	0.6°C
$300T_0$	$400\text{-}300H_0$, $300T_{-12}$	727	0.74°C		1.71°C			
$250Z_0$	$300Z_0$, $300T_0$	733	31.7 ft	19.0 ft	93.7 ft	106.3 ft	17.7 ft	15.7 ft
$250T_0$	$300T_0$, $250T_{-12}$, $300\text{-}250H_0$	733	0.55°C	0.5°C	1.72°C	1.8°C	0.7°C	0.6°C
$200Z_0$	$250Z_0$, $250T_0$	733	30.5 ft	17.0 ft	114.2 ft	133.2 ft	20.7 ft	21.3 ft
$200T_0$	$250\text{-}200H_0$	733	0.59°C	0.7°C	1.56°C	1.5°C	0.6°C	0.4°C
$150Z_0$	$200Z_0$, $200T_0$	625	40.0 ft	29.7 ft	140.4 ft	128.3 ft	20.7 ft	27.9 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $200Z_0$	625	0.79°C	1.0°C	1.63°C	2.0°C	1.0°C	0.8°C
$100Z_0$	$150Z_0$, $150\text{-}100H_{-12}$	625	77.6 ft	65.8 ft	131.8 ft	279.1 ft	53.5 ft	60.4 ft
$100T_0$	$100T_{-12}$, $150\text{-}100H_0$	625	1.78°C	1.9°C	2.99°C	3.2°C	1.6°C	2.2°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

† Fifty independent cases for each predictand.

‡ Twenty-five cases for each predictand.

July, 25–35°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jul. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Jun. r.m.s.e.‡	Aug. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	753	29.3 ft		117.7 ft			
$400T_0$	$500\text{-}400H_0$, $500T_0$, $400T_{-12}$	753	0.74°C		1.75°C			
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	753	55.2 ft	44.9 ft	145.7 ft	160.8 ft	53.8 ft	34.5 ft
$300Z_0$	$400Z_0$, $400T_0$	753	40.5 ft		145.7 ft			
$300T_0$	$500\text{-}300H_0$, $300T_{-12}$, $500\text{-}300T_{m,-12}$	753	0.86°C	0.8°C	1.80°C	2.7°C	0.9°C	0.9°C
$300T_0$	$400\text{-}300H_0$, $300T_{-12}$	753	0.85°C		1.80°C			
$250Z_0$	$300Z_0$, $300T_0$	761	38.0 ft	19.0 ft	159.7 ft	197.0 ft	26.6 ft	15.7 ft
$250T_0$	$300\text{-}250H_0$, $250T_{-12}$	761	0.91°C	1.0°C	1.66°C	2.6°C	0.8°C	0.7°C
$200Z_0$	$250Z_0$, $250T_0$	761	40.9 ft	22.6 ft	173.1 ft	199.2 ft	35.4 ft	21.0 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	761	0.71°C	0.8°C	1.68°C	2.5°C	0.8°C	0.6°C
$150Z_0$	$200Z_0$, $200T_0$	760	47.9 ft	32.3 ft	172.7 ft	232.3 ft	49.2 ft	31.2 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$	760	0.98°C	0.9°C	2.36°C	3.1°C	1.1°C	1.1°C
$100Z_0$	$150Z_0$, $150\text{-}100H_{-12}$	760	76.2 ft	42.7 ft	161.9 ft	177.6 ft	52.8 ft	55.4 ft
$100T_0$	$100T_{-12}$, $150\text{-}100H_0$, $150T_0$	760	1.78°C	1.3°C	2.87°C	3.2°C	1.8°C	1.8°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

July, 35–45°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jul. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Jun. r.m.s.e.‡	Aug. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	1056	33.7 ft		220.4 ft			
$400T_0$	$500\text{-}400H_0$, $500T_0$	1056	0.72°C		2.81°C			
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	1056	60.2 ft	45.3 ft	282.6 ft	292.2 ft	42.0 ft	72.2 ft
$300Z_0$	$400Z_0$, $400T_0$	1056	34.4 ft		282.6 ft			
$300T_0$	$500\text{-}300H_0$, $500T_0$	1056	0.86°C	1.0°C	3.02°C	3.5°C	0.9°C	1.4°C
$300T_0$	$400\text{-}300H_0$	1056	0.80°C		3.02°C			
$250Z_0$	$300Z_0$, $300T_0$	1053	36.4 ft	15.2 ft	321.1 ft	328.2 ft	20.0 ft	14.1 ft
$250T_0$	$300\text{-}250H_0$, $250T_{-12}$	1053	0.94°C	0.8°C	2.81°C	3.4°C	0.6°C	1.2°C
$200Z_0$	$250Z_0$, $250T_0$	1053	47.8 ft	27.4 ft	348.4 ft	360.4 ft	36.6 ft	23.3 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	1053	0.90°C	1.3°C	2.46°C	3.2°C	1.3°C	0.7°C
$150Z_0$	$200Z_0$, $200T_0$	973	58.3 ft	41.6 ft	298.6 ft	317.2 ft	74.1 ft	24.0 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $150T_{-12}$	973	1.35°C	1.6°C	4.29°C	2.2°C	1.5°C	1.4°C
$100Z_0$	$150Z_0$, $150\text{-}100H_{-12}$, $150T_0$, $100Z_{-12}$	973	80.5 ft	59.5 ft	199.3 ft	209.6 ft	70.5 ft	66.6 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$	973	1.78°C	1.3°C	4.33°C	3.8°C	1.4°C	1.8°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

July, 45–55°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jul. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Jun. r.m.s.e.‡	Aug. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	764	30.7 ft		395.1 ft			
$400T_0$	$500\text{-}400H_0$	764	0.85°C		3.83°C			
$300Z_0$	$500Z_0$, $500T_0$	764	58.1 ft	55.7 ft	479.6 ft	546.9 ft	61.7 ft	50.5 ft
$300Z_0$	$400Z_0$, $400T_0$	764	40.1 ft		479.6 ft			
$300T_0$	$500\text{-}300H_0$, $500T_0$	764	1.15°C	0.9°C	3.46°C	4.1°C	1.5°C	1.1°C
$300T_0$	$400\text{-}300H_0$, $400T_0$	764	0.83°C		3.46°C			
$250Z_0$	$300Z_0$, $300T_0$	759	33.4 ft	19.9 ft	511.0 ft	602.8 ft	24.9 ft	25.6 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	759	1.07°C	1.2°C	3.17°C	3.0°C	0.7°C	1.5°C
$200Z_0$	$250Z_0$, $250T_0$	759	51.7 ft	41.0 ft	476.2 ft	557.0 ft	53.6 ft	45.3 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$, $200T_{-12}$, $250Z_0$	759	1.56°C	1.6°C	5.13°C	4.7°C	2.1°C	1.1°C
$150Z_0$	$200Z_0$, $200T_0$	689	59.8 ft	48.3 ft	371.7 ft	455.6 ft	67.5 ft	44.9 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $200Z_0$	689	1.26°C	1.2°C	4.38°C	4.6°C	2.0°C	1.4°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$, $100Z_{-12}$	689	64.5 ft	65.5 ft	255.5 ft	319.3 ft	50.7 ft	50.9 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$	689	1.38°C	1.2°C	3.76°C	4.2°C	1.5°C	1.7°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

July, 55–65°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jul. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Jun. r.m.s.e.‡	Aug. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	847	32.7 ft		394.5 ft			
$400T_0$	$500\text{-}400H_0$	847	1.12°C		4.03°C			
$300Z_0$	$500Z_0$, $500T_0$	847	66.9 ft	48.5 ft	474.1 ft	460.8 ft	85.9 ft	54.5 ft
$300Z_0$	$400Z_0$, $400T_0$	847	42.8 ft		474.1 ft			
$300T_0$	$500\text{-}300H_0$, $500T_0$, $300T_{-12}$	847	1.45°C	1.4°C	3.38°C	3.0°C	2.2°C	2.1°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	847	1.14°C		3.38°C			
$250Z_0$	$300Z_0$, $300T_0$	827	37.4 f-	32.7 ft	488.6 ft	472.7 ft	27.1 ft	38.7 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$, $250T_{-12}$	827	1.31°C	1.1°C¶	3.97°C	4.2°C¶	0.7°C	1.4°C
$200Z_0$	$250Z_0$, $250T_0$	827	58.6 ft	35.3 ft¶	418.4 ft	407.6 ft¶	56.9 ft	65.9 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$, $200T_{-12}$	827	1.70°C	1.4°C¶	6.05°C	5.8°C¶	0.9°C	2.0°C
$150Z_0$	$200Z_0$, $200T_0$	770	54.5 ft	31.9 ft	344.6 ft	320.9 ft	36.4 ft	37.1 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$	770	0.89°C	0.9°C	3.32°C	3.3°C	0.8°C	0.9°C
$100Z_0$	$150Z_0$, $150T_0$, $100Z_{-12}$	770	79.0 ft	51.5 ft¶	316.6 ft	275.6 ft¶	61.1 ft	51.5 ft
$100T_0$	$150\text{-}100H_0$, $150T_0$, $100T_{-12}$, $150\text{-}100T_{m,-12}$	770	1.04°C	0.7°C¶	2.43°C	2.3°C¶	1.0°C	1.1°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand except 49 if marked by ¶.

‡Twenty-five cases for each predictand.

¶Forty-nine cases for this predictand.

July, 65–90°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Jul. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Jun. r.m.s.e.‡	Aug. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	782	31.7 ft		351.1 ft			
$400T_0$	$500\text{-}400H_0$	782	0.94°C		3.82°C			
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	782	61.5 ft	45.2 ft	416.3 ft	450.7 ft	45.3 ft	57.7 ft
$300Z_0$	$400Z_0$, $400T_0$	782	44.7 ft		416.3 ft			
$300T_0$	$300T_{-12}$, $500\text{-}300H_0$, $500T_0$	782	1.51°C	1.5°C	3.32°C	3.02°C	1.3°C	1.5°C
$200T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	782	1.18°C		3.32°C			
$250Z_0$	$300Z_0$, $300T_0$	783	43.4 ft	25.9 ft	404.6 ft	441.1 ft	27.9 ft	42.0 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$, $250T_{-12}$	783	1.46°C	1.1°C¶	4.46°C	4.4°C¶	1.2°C	1.4°C
$200Z_0$	$250Z_0$, $250T_0$	783	50.7 ft	39.1 ft	333.5 ft	359.8 ft	66.6 ft	57.4 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$, $200T_{-12}$	783	1.38°C	1.2°C	4.69°C	4.0°C	1.7°C	1.1°C
$150Z_0$	$200Z_0$, $200T_0$	725	49.2 ft	19.5 ft	267.8 ft	300.0 ft	31.5 ft	43.3 ft
$150T_0$	$200\text{-}150H_0$	725	0.93°C	0.6°C	2.73°C	2.3°C	0.6°C	0.9°C
$100Z_0$	$150Z_0$, $150T_0$, $100Z_{-12}$	725	69.5 ft	51.6 ft	260.7 ft	262.3 ft	57.4 ft	46.6 ft
$100T_0$	$150T_0$, $100T_{-12}$, $150\text{-}100H_0$, $150\text{-}100T_{m,-12}$	725	0.84°C	0.8°C	2.50°C	1.9°C	0.9°C	0.9°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand except 49 if marked by ¶.

‡Twenty-five cases for each predictand.

¶Forty-nine cases for this predictand.

October, 0–25°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Oct. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Sep. r.m.s.e.‡	Nov. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	786	30.2 ft	19.6 ft	82.3 ft	74.5 ft	13.3 ft	19.8 ft
$400T_0$	$500\text{-}400H_0$, $400T_{-12}$, $500T_0$	786	0.70°C	0.8°C	1.60°C	1.95°C	0.6°C	0.7°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	786	53.0 ft	39.5 ft	108.5 ft	112.7 ft	32.0 ft	40.3 ft
$300Z_0$	$400Z_0$, $400T_0$	786	41.5 ft	24.0 ft	108.5 ft	112.7 ft	20.0 ft	37.5 ft
$300T_0$	$500\text{-}300H_0$, $300T_{-12}$, $500T_0$	786	0.74°C	0.7°C	1.74°C	2.14°C	0.5°C	0.9°C
$300T_0$	$400\text{-}300H_0$, $300T_{-12}$	786	0.71°C	0.6°C	1.74°C	2.14°C	0.5°C	0.7°C
$250Z_0$	$300Z_0$, $300T_C$	772	30.8 ft	14.6 ft	123.4 ft	137.8 ft	9.1 ft	19.9 ft
$250T_0$	$300T_0$, $300\text{-}250H_0$, $250T_{-12}$	772	0.62°C	0.6°C	1.69°C	1.84°C	0.5°C	0.8°C
$200Z_0$	$250Z_0$, $250T_0$	772	34.4 ft	15.9 ft	146.4 ft	165.9 ft	12.1 ft	29.0 ft
$200T_0$	$250\text{-}200H_0$, $200T_{-12}$, $250\text{-}200T_{m,-12}$	772	0.63°C	0.6°C	1.62°C	1.56°C	0.6°C	1.0°C
$150Z_0$	$200Z_C$, $200T_0$	692	39.0 ft	26.3 ft	163.1 ft	176.8 ft	19.2 ft	36.1 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $150T_{-12}$	692	0.77°C	0.8°C	1.84°C	1.74°C	0.9°C	0.7°C
$100Z_0$	$150Z_0$, $150\text{-}100H_{-12}$, $150T_0$	692	69.8 ft	44.4 ft	155.5 ft	147.6 ft	55.0 ft	49.7 ft
$100T_0$	$100T_{-12}$, $150\text{-}100H_0$	692	1.61°C	1.8°C	2.86°C	3.23°C	1.8°C	1.0°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

October, 25–35°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Oct. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Sep. r.m.s.e.‡	Nov. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	807	30.6 ft	26.4 ft	252.1 ft	357.6 ft	17.9 ft	24.7 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	807	0.83°C	0.8°C	3.38°C	3.31°C	0.8°C	0.9°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	807	59.1 ft	64.0 ft	324.3 ft	431.5 ft	39.2 ft	61.2 ft
$300Z_0$	$400Z_0$, $400T_0$	807	44.4 ft	25.8 ft	324.3 ft	431.5 ft	21.7 ft	32.3 ft
$300T_0$	$500\text{-}300H_0$, $300T_{-12}$, $500T_0$	807	0.95°C	0.9°C	3.31°C	2.88°C	0.9°C	1.1°C
$300T_0$	$400\text{-}300H_0$, $300T_{-12}$, $400T_0$	807	0.81°C	0.8°C	3.31°C	2.88°C	0.7°C	0.8°C
$250Z_0$	$300Z_0$, $300T_0$	795	35.5 ft	17.1 ft	366.7 ft	453.2 ft	11.7 ft	18.9 ft
$250T_0$	$300\text{-}250H_0$, $250T_{-12}$, $300\text{-}250T_{m,-12}$	795	0.92°C	1.1°C	3.02°C	2.25°C	0.5°C	0.9°C
$200Z_0$	$250Z_0$, $250T_0$	795	45.3 ft	23.2 ft	396.9 ft	443.9 ft	18.1 ft	25.9 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$, $200T_{-12}$	795	0.95°C	0.8°C	2.35°C	2.69°C	0.8°C	1.0°C
$150Z_0$	$200Z_0$, $200T_0$	701	47.4 ft	33.8 ft	373.1 ft	392.2 ft	35.5 ft	38.6 ft
$150T_0$	$150T_{-12}$, $200\text{-}150H_0$, $200T_0$	701	0.97°C	0.9°C	2.99°C	3.84°C	0.8°C	1.1°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	701	61.5 ft	50.4 ft	270.6 ft	282.1 ft	59.9 ft	84.8 ft
$100T_0$	$100T_{-12}$, $150\text{-}100H_0$	701	1.50°C	1.6°C	4.17°C	3.90°C	1.4°C	1.6°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

October, 35–45°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Oct. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Sep. r.m.s.e.‡	Nov. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	1110	35.3 ft	16.3 ft	386.5 ft	387.4 ft	20.6 ft	22.1 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	1110	0.86°C	0.7°C	3.96°C	3.65°C	0.8°C	0.6°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	1110	58.1 ft	53.8 ft	467.0 ft	470.3 ft	37.6 ft	57.0 ft
$300Z_0$	$400Z_0$, $400T_0$	1110	37.1 ft	30.5 ft	467.0 ft	470.3 ft	22.5 ft	35.1 ft
$300T_0$	$500\text{-}300H_0$, $500T_0$, $300T_{-12}$	1110	1.19°C	1.0°C	3.49°C	3.66°C	1.0°C	1.2°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	1110	0.91°C	0.9°C	3.49°C	3.66°C	0.8°C	0.9°C
$250Z_0$	$300Z_0$, $300T_0$	1111	42.6 ft	18.8 ft	503.7 ft	511.9 ft	19.4 ft	32.8 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$, $250T_{-12}$	1111	0.85°C	3.45°C	3.17°C	3.45°C	1.4°C	0.8°C
$200Z_0$	$250Z_0$, $250T_0$	1111	50.4 ft	28.4 ft	507.6 ft	523.5 ft	32.9 ft	30.7 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	1111	1.07°C	1.0°C	3.55°C	3.81°C	1.2°C	1.1°C
$150Z_0$	$200Z_0$, $200T_0$	994	51.1 ft	36.1 ft	459.3 ft	473.7 ft	28.7 ft	63.2 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$, $200Z_0$	994	1.14°C	1.5°C	3.57°C	4.01°C	1.2°C	1.8°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$, $100Z_{-12}$	994	69.6 ft	61.2 ft	345.1 ft	313.7 ft	42.1 ft	68.7 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$, $150T_0$	994	1.44°C	1.4°C	4.05°C	4.84°C	1.7°C	1.7°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

October, 45–55°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Oct. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Sep. r.m.s.e.‡	Nov. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	713	34.0 ft	20.6 ft	574.0 ft	583.5 ft	15.4 ft	37.9 ft
$400T_0$	$500\text{-}400H_0$	713	1.17°C	1.1°C	5.29°C	5.73°C	0.9°C	1.6°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	713	73.0 ft	78.7 ft	670.1 ft	692.3 ft	56.8 ft	104.6 ft
$300Z_0$	$400Z_0$, $400T_0$	713	43.4 ft	32.4 ft	670.1 ft	692.3 ft	26.2 ft	47.8 ft
$300T_0$	$500\text{-}300H_0$, $500T_0$, $300T_{-12}$	713	1.58°C	1.6°C	3.96°C	4.19°C	1.1°C	1.8°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	713	1.21°C	1.0°C	3.96°C	4.19°C	0.9°C	1.0°C
$250Z_0$	$300Z_0$, $300T_0$	707	39.9 ft	25.2 ft	693.7 ft	718.2 ft	26.6 ft	40.2 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	707	1.13°C	1.1°C	3.91°C	4.41°C	0.9°C	1.1°C
$200Z_0$	$250Z_0$, $250T_0$	707	74.9 ft	41.0 ft	653.2 ft	471.9 ft	48.9 ft	58.0 ft
$200T_0$	$250\text{-}200H_0$, $200T_{-12}$, $250Z_0$, $250T_0$	707	2.25°C	2.4°C	5.42°C	5.68°C	2.8°C	3.2°C
$150Z_0$	$200Z_0$, $200T_0$	616	58.5 ft	33.1 ft	555.8 ft	587.3 ft	65.5 ft	64.8 ft
$150T_0$	$200\text{-}150H_0$, $200Z_0$	616	1.62°C	1.3°C	5.14°C	4.61°C	2.1°C	2.6°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$, $100Z_{-12}$	616	62.8 ft	46.6 ft	410.4 ft	449.9 ft	44.6 ft	57.9 ft
$100T_0$	$150\text{-}100H_0$, $150T_0$	616	1.55°C	1.7°C	4.70°C	4.74°C	1.4°C	1.5°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.

October, 55–65°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Oct. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Sep. r.m.s.e.‡	Nov. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	865	33.6 ft	31.9 ft	537.0 ft	759.4 ft	12.7 ft	21.8 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	865	1.03°C	0.8°C	5.47°C	5.41°C	0.7°C	0.9°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	865	79.5 ft	78.0 ft	636.0 ft	784.4 ft	46.3 ft	82.0 ft
$300Z_0$	$400Z_0$, $400T_0$	865	51.0 ft	42.0 ft	636.0 ft	784.4 ft	29.8 ft	45.0 ft
$300T_0$	$500\text{-}300H_0$, $500T_0$, $300T_{-12}$	865	1.84°C	2.1°C	4.36°C	3.66°C	1.5°C	1.6°C
$300T_0$	$400\text{-}300H_0$, $400T_0$, $300T_{-12}$	865	1.44°C	1.4°C	4.36°C	3.66°C	1.0°C	0.9°C
$250Z_0$	$300Z_0$, $300T_0$	856	39.9 ft	29.9 ft	648.1 ft	780.3 ft	17.7 ft	30.0 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$	856	1.27°C	1.1°C	4.48°C	4.9°C	1.3°C	1.1°C
$200Z_0$	$250Z_0$, $250T_0$	856	48.2 ft	36.1 ft	603.6 ft	708.6 ft	61.5 ft	52.2 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	856	1.27°C	1.5°C	4.78°C	6.24°C	1.5°C	1.2°C
$150Z_0$	$200Z_0$, $200T_0$	782	52.0 ft	35.8 ft	524.8 ft	599.4 ft	64.1 ft	39.0 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$	782	1.06°C	1.2°C	3.74°C	4.74°C	1.6°C	0.9°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	782	59.9 ft	44.6 ft	449.9 ft	489.1 ft	43.0 ft	33.1 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$	782	1.30°C	1.4°C	3.50°C	3.90°C	0.9°C	1.1°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.
† Fifty independent cases for each predictand.
‡ Twenty-five cases for each predictand.

October, 65–90°N

Predictand*	Selected predictors*	Number of dep. cases	R.m.s.e.		Std. dev.		Ind. data with Oct. eqs.	
			Dep.	Ind.†	Dep.	Ind.†	Sep. r.m.s.e.‡	Nov. r.m.s.e.‡
$400Z_0$	$500Z_0$, $500T_0$	846	31.7 ft	18.4 ft	420.3 ft	385.1 ft	32.4 ft	23.5 ft
$400T_0$	$500\text{-}400H_0$, $500T_0$	846	0.93°C	0.6°C	4.47°C	4.43°C	0.8°C	1.0°C
$300Z_0$	$500Z_0$, $500T_0$, $500\text{-}300H_{-12}$	846	67.3 ft	56.1 ft	491.2 ft	454.4 ft	119.8 ft	64.9 ft
$300Z_0$	$400Z_0$, $400T_0$	846	45.7 ft	33.1 ft	491.2 ft	454.4 ft	52.7 ft	41.7 ft
$300T_0$	$300T_{-12}$, $500\text{-}300H_0$, $500T_0$	846	1.44°C	1.7°C	3.50°C	2.85°C	1.4°C	1.6°C
$300T_0$	$400\text{-}300H_0$, $400T_0$	846	0.99°C	1.1°C	3.50°C	2.85°C	1.2°C	1.1°C
$250Z_0$	$300Z_0$, $300T_0$	820	41.0 ft	30.3 ft	492.1 ft	444.4 ft	45.3 ft	29.9 ft
$250T_0$	$300\text{-}250H_0$, $300T_0$, $250T_{-12}$	820	1.17°C	1.2°C	4.33°C	3.87°C	1.1°C	1.0°C
$200Z_0$	$250Z_0$, $250T_0$	820	49.1 ft	36.5 ft	465.0 ft	402.6 ft	55.3 ft	34.9 ft
$200T_0$	$250\text{-}200H_0$, $250T_0$	820	0.98°C	0.9°C	3.46°C	3.16°C	1.6°C	1.1°C
$150Z_0$	$200Z_0$, $200T_0$	767	44.5 ft	26.4 ft	458.0 ft	376.4 ft	35.0 ft	25.6 ft
$150T_0$	$200\text{-}150H_0$, $200T_0$	767	0.75°C	0.6°C	2.44°C	2.25°C	0.8°C	1.0°C
$100Z_0$	$150Z_0$, $150T_0$, $150\text{-}100H_{-12}$	767	45.5 ft	30.3 ft	476.9 ft	355.1 ft	22.8 ft	40.7 ft
$100T_0$	$150\text{-}100H_0$, $100T_{-12}$, $150Z_0$	767	0.86°C	0.9°C	2.68°C	2.38°C	1.1°C	1.4°C

*H, T, and Z are thickness of layer between constant-pressure surfaces, temperature at constant-pressure surface, and height of constant-pressure surface, respectively. Subscript 0 designates observation time, subscript -12 designates 12 hr before observation, and subscript m designates a mean over a layer.

†Fifty independent cases for each predictand.

‡Twenty-five cases for each predictand.